SINGLE OBJECTIVE OPTIMIZATION OF EDM MACHINING ON TITANIUM WORKPIECE USING TAGUCHI METHOD

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Thesis submitted in fulfilment of the requirements
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “SINGLE OBJECTIVE OPTIMIZATION OF EDM MACHINING ON TITANIUM WORKPIECE USING TAGUCHI METHOD” is written by Wan MohdAriff Bin Wan Azli. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilments of the requirements for the degree of Bachelor of Mechanical with Manufacturing Engineering.

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ABSTRACT

Electrical discharge machining (EDM) is a process for shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electro-conductive materials. The objective of this paper is to investigate how the polarity, peak current, pulse on duration, pulse off duration and servo voltage in EDM effect on material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). The effectiveness of EDM process with titanium alloy (Ti-6Al-4V)through electrical discharge machining (EDM) using copper tungsten (CuW)as an electrode.It is observed that copper tungsten (CuW) is most suitable for use as the tool electrode in EDM of Ti-6Al-4V .Better machining performance is obtained generally with the electrode as the cathode and the workpiece as an anode. In this research, a study was carried out on the influence of the parameters such as polarity, peak current, pulse on duration, pulse off duration and servo voltage. The surface quality that was investigated in this experiment was surface roughness using perthometer machine. Material removal rate (MRR) and electrode wear (EW) in this experiment was calculated by using mathematical method. The result of the experiment then was collected and analyzed using MINITAB software. This was done by using the technique of design of experiments (DOE) and technique such as ANOVA analysis. This analysis was purposed to select the optimal machining condition for use in confirmation test.

ABSTRAK

Nyahcaselektrikmemesin (EDM) ialahsatu proses untukmembentuklogamkerasdanmembentuklubang-lubangberbentukkompleksolehhakisanarkadalamsemuajenisbahan yang mengalirkanelektrik. Tujuankajianiniialahuntukmenyiasatfaktorkekutuban, aruspuncak, denyut di tempoh, denyutdarivoltantempohdanvoltan servo yang memberikesankepadakadarpemesinanbahan (MRR), kadarkehausanalat (TWR) dankekasaranpermukaan (SR). Keberkesanan proses nyahcaselektrikmesin (EDM) dengan (Ti-6Al-4V)melaluinyahcaselektrikmemesin (EDM) menggunakan (CuW) sebagaisatuelektrod. Diperhatikan yang (CuW) paling sesuaiuntukkegunaansebagaielektrodalatdalamnyahcaselektrikmesin (EDM) bagi (Ti 6Al 4V) .Prestasipermesinan yang baikdiperolehipadaumumnyadenganelektrodsebagaikatoddanbahansebagaianod. Dalampenyelidikanini, satukajiantelahdijalankandipengaruhioleh parameter sepertikekutuban, aruspuncak, denyut di tempoh, denyutdarivoltantempohdanvoltan servo. Kualitipermukaandalameksperimeninidiperolehikekasaranpermukaannyadenganmenggunakanmesinperthometer. Kadar pemesinanbahan (MRR) dankehausanalat (TWR) dalameksperimeninidikiradenganmenggunakankaedahmatematik. Hasileksperimenkemudiandipungutkandandianalisismenggunakanperisian MINITAB.Inidilakukandenganmenggunakankaedahdesaineksperimen (DOE) dantekniksepertianalisis ANOVA.Analisisinibertujuanuntukmemilihkeadaanpermesinan yang optimum bagikegunaandalamujianpengesahan.

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μ	Unit microsecond
$\varnothing$	Diameter
Ω	Ohm
W_{pi}	Sample initial weight
W_{pf}	Sample final weight
W_{ei}	Electrode initial weight
W_{ef}	Electrode final weight
T	Time in minute
R_a	Measured to quantitatively evaluate how EDM parameters affect the surface finish

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machine
CuW	Copper Tungsten
MRR	Material Removal Rate
EWR	Electrode Wear Ratio
SR	Surface Roughness
ANOVA	Analysis of Variance
DC	Direct Current
DOE	Design of Experiments
WRW	Workpiece Removal Weight
EWW	Electrode Wear Weight
OA	Orthogonal Array
PV	Predicted Value
CI	Confidence Interval

CHAPTER 1

INTRODUCTION

1.1 ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. Electrical discharge machining process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporizing. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using electrical discharge machining such as dies and moulds.. The moving of tool electrode, up and down, in Z axis only introduces new dielectric fluid into the cavity of the workpiece. When the electrode is cycled down, it pushes out the contaminated oil. Injection flushing is where the dielectric fluid is forced down through a flushing hole in the tool electrode.

The workpiece material used in this study is a titanium alloy and the tools is using copper tungsten that hard and can be cut the titanium alloy. The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). The control parameters optimization for individualmachining characteristic is concerned with separately maximize the material removal rate, separately minimize the tool wear ratio and separately obtained a good surface finish. There are many input parameters which can be varied in the EDM process which have different effects on the EDM machining characteristics.

In this paper, the use of the Taguchi method to determine the electric discharge machining process parameters. This is because the Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality at the design stage (Y. M. Zhang, R. Kovacevic, and L. Li, (1996)), S. C. Juang, Y. S. Tarng, and H.R. Lii (1998)). By using this method, we can determine and find the suitable parameter to optimize the electrical discharge machine on titanium workpiece. This project is to investigate the optimum parameter required for MRR, EWR and SR by using Taguci method.

1.2 IMPORTANCE OF RESEARCH

The important of doing this research are:-

1) Improve the quality surface finish of the cut metal.
2) Improve efficiency of production process by increasing the machining process performance and lowering the manufacturing cost.
3) Minimize the time and cost of production process by using L18 orthogonal array because it suitable experimental plan to optimize the machining parameters easier than than using full factorial experimental plan.
4) Enhance the production rate.
5) Analysis of Variance (ANOVA) is being used for the data analysis of maximizing the material removal rate (MRR), minimizing electrode wear ratio (EWR) and minimizing surface roughness (SR).

1.3 PROBLEM STATEMENT

During the machining process, wear will occur on the electrode. This will affect the machining efficiency and cost. Other than that, the optimum parameter is also problems occur in this project. The optimum parameter can affect and meanwhile optimize the EDM process. For rough machining that related to material removal rate (MRR), minimum MRR will decrease the machining productivity. For intermediate machining that related to electrode wear ratio (EWR), higher EWR will affect more on dimensional precision of the machined workpiece. Beside that, for fine machining related to surface roughness (SR), higher surface roughness will produce a very poor surface integrity.

1.4 OBJECTIVE OF RESEARCH

The objective of this thesis is to optimize the surface roughness (SR), electrode wear ratio (EWR) and material removal rate (MRR) by taguci method and to discuss on the

significant factors by using analysis of variance (ANOVA).

1.5 SCOPE OF RESEARCH

The research is limited to single machining characteristics control parameters optimization. The machining characteristics mentioned are material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) because each type of EDM machining i.e. rough machining, intermediate machining or fine machining requires single machining characteristic of control parameters optimization.

1.6 RESEARCH FLOW CHART

The flow chart of this research is illustrated in figure 1 below:-

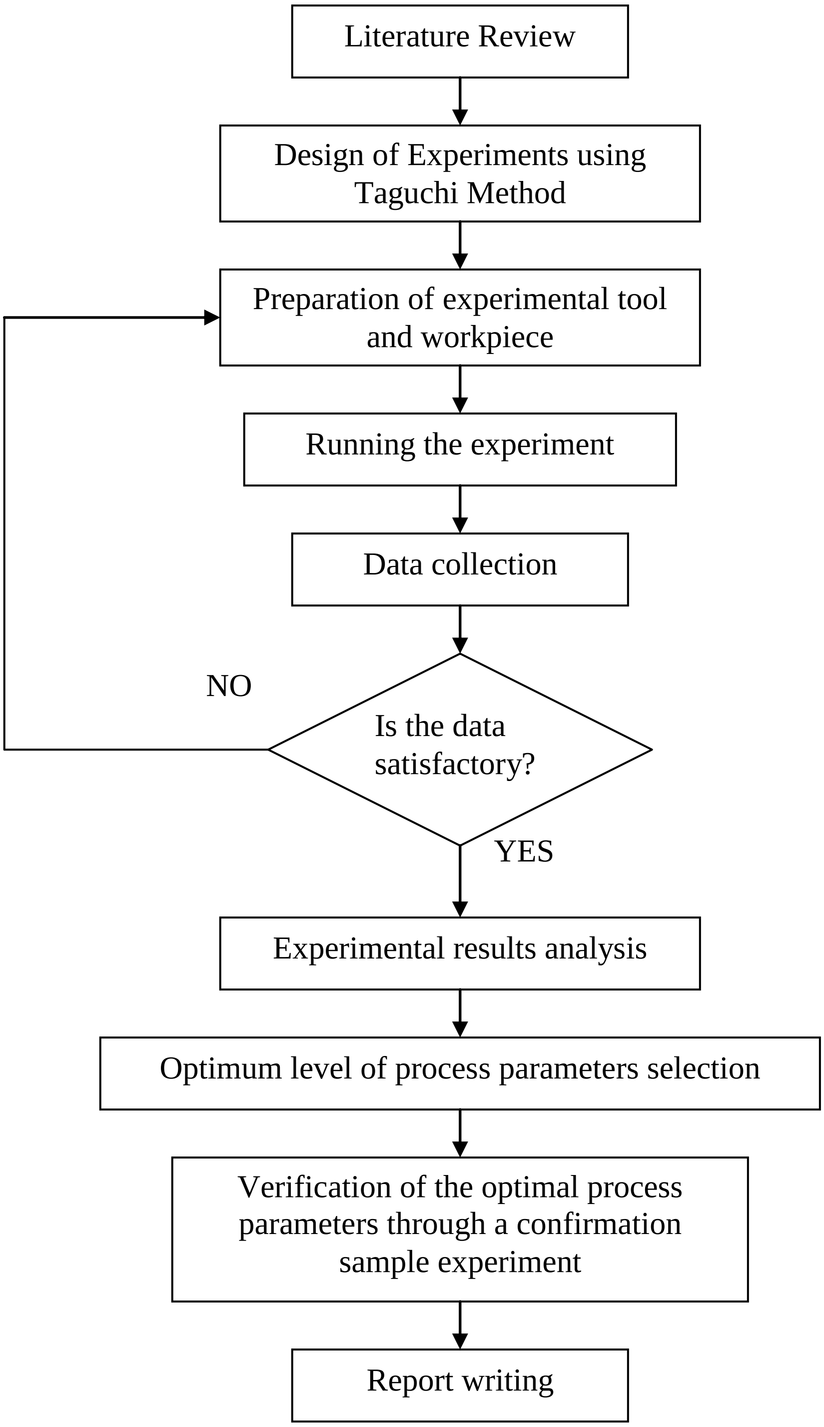


Figure 1: Research Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discuss on some literatures about EDM process, parameters and methods involved in this project. A literature review is a body of text that aims to review the critical points of current knowledge and studies related to the project. In 1970, the English scientist, Priestley, first detected the erosive effect of electrical discharges on metals. More recently, during research (to eliminate erosive effects on electrical contacts) the soviet scientists, Lazarenko and Lazarenko, decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943, they announced the construction of the first spark erosion machining. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and an improved form is being used in many current application. The EDM process can be compared with the conventional cutting process, except that in this case, a suitably shaped tool electrode, with a precision controlled feed movement is employed in place of the cutting tool and the cutting energy is provided by means of short duration electrical impulses. It thus plays a major role in the machining of dies, tools, etc., made of tungsten carbides, stellites or hard steels. Alloys used in the aeronautics industry, for example, hastalloy, nimonic, etc., could also be machined conveniently by this process. EDM is also used to machining of exotic materials, refractory metals and hard enable steels. This process has an added advantage of being capable of machining complicated components and making intricate shapes. Most of the surgical components are being machined by this process since EDM is one of the unconventional processes which can produce better surface quality.

2.2 PRINCIPLES OF EDM OPERATION

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece.

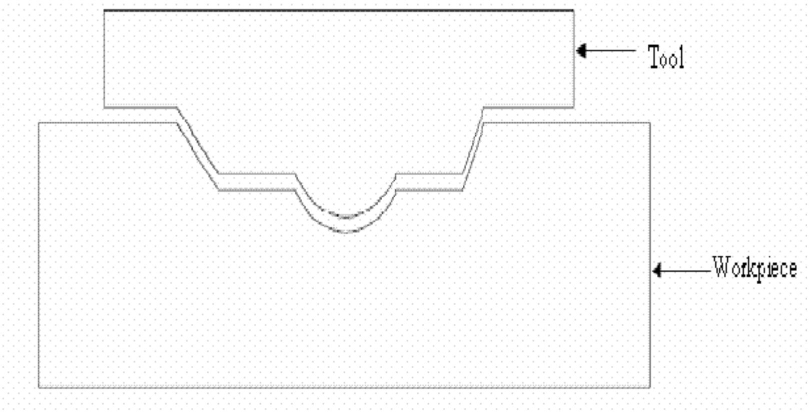


Figure 2.0 : Tool shape and corresponding cavity formed on work piece after EDM Operation

Source: Lazarenko :R-C circuit EDM [EDM](2008)

Thus, a replica of the tool surface shape is formed on the work piece as shown in figure 2.0. If the tool is held stationary, machining would stop at this stage. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the work piece.

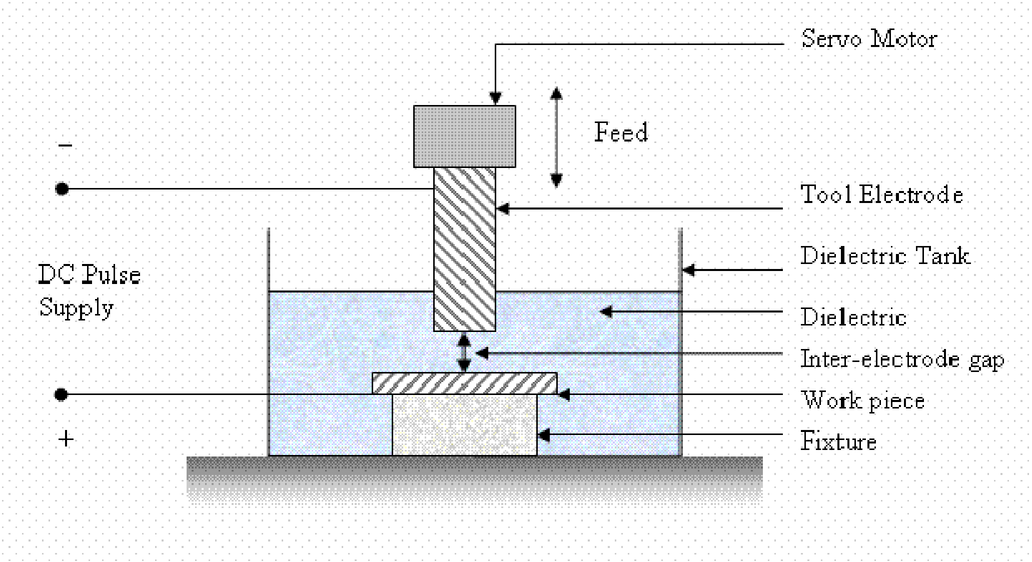


Figure 2.1 :Schematic diagram of basic EDM System

Source: Lazarenko :R-C circuit EDM [EDM](2008)

The schematic of an EDM machine tool is shown in figure 2.1.The tool and the work piece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the work piece is generally provided for maintaining a constant gap distance between the tool and the work piece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the work piece, the tool is moved downward towards the work piece to maintain a constant inter-electrode gap. The tool and the work piece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap. Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the work piece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300 cubic mm/min can be achieved during EDM.

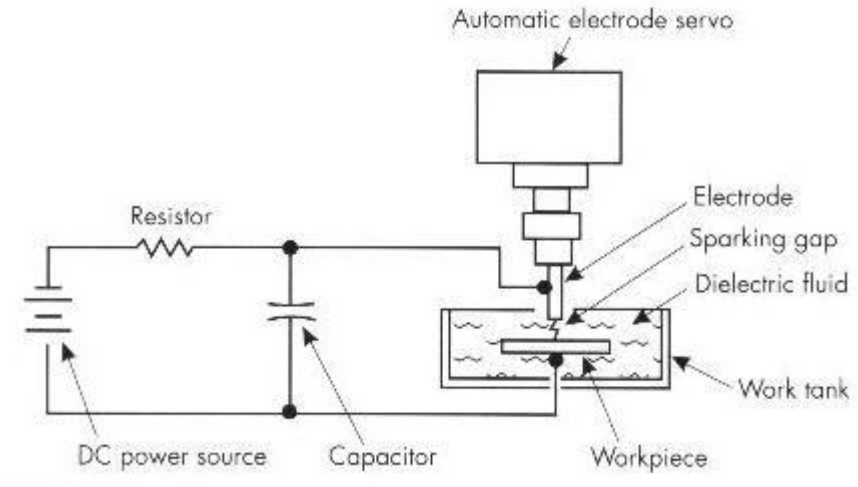


Figure 2.2 :Spark initiation in EDM process

Source: Anti TRIZ Journal [EDM](2009)

Figure 2.2 shows the workpiece is mounted on the table of the machine tool and the electrode is attached to the ram of the machine. A DC servo unit or hydraulic cylinder moves the ram (and electrode) in a vertical motion and maintains proper position of the electrode in relation to the workpiece. The positioning is controlled automatically and with extreme accuracy by the servo system and power supply. During normal operation the electrode never touches the workpiece, but is separated by a small spark gap. During operation, the ram moves the electrode toward the workpiece until the space between them is such that the voltage in the gap can ionize the dielectric fluid and allow an electrical discharge (spark) to pass from the electrode to the workpiece.

The benefits of EDM include:
i) EDM is a non-contact process that generates no cutting forces, permitting the production of small and fragile pieces.
ii) EDM machines with built-in process knowledge allow the production of intricate parts with minimum operator intervention.
iii) Burr-free edges are produced.

Limitations of EDM are :
There are quite a number of problems still to be solved to enable the process to be adopted on an extensive process.

1. Lower Material Removal Rate (MRR) , Poor Surface Quality(SQ) are the real time EDM process limitations. In other words, maximizing the MRR, minimizing the surface roughness value [9] are the real time EDM process objectives.
2. The wear rate on the electrode is considerably higher. Sometimes it may be necessary to use more than one electrode to finish the job.
3. The work piece should be electrically conductive to be machined.
4. The energy required for the operation is more than that of the conventional process and hence will be more expensive.
5. Environmental concerns associated with the process have been a major drawback of EDM. The dielectric fluid used in EDM is the primary source of pollution from the process. Hydrocarbon based oils are the most commonly used EDM dielectric. Dielectric wastes generated after machining are very toxic and cannot be recycled. Also, toxic fumes are generated due to high temperature chemical breakdown of dielectric during machining. The use of oil as the dielectric fluid also makes it necessary to take extra precaution to prevent fire hazards. Since an environment friendly alternative for replacing the EDM process is not available, changing or totally eliminating the liquid dielectric medium provides a feasible solution.

2.3 DIE-SINKING EDM MACHINE

Die-sinking EDM machines are also known as ram or vertical EDMs. Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was kerosene. Figure 2.1 show the schematic diagram of basic EDM system.

Die-sinking EDM have four sub-systems that are:

i) DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.
ii) Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.
iii) Consumable electrode.
iv) Servo system to control infeed of the electrode and provide gap maintenance.

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionise when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.

Generally kerosene and deionised water is used as dielectric fluid in EDM. Tap water cannot be used as it ionises too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

Kerosene dielectric gives lower relative tool wear values compared with the other dielectrics for a low to medium range of current.

The functions of the dielectric fluid are to:

i) Act as an insulator between the tool and the workpiece.
ii) Act as coolant.
iii) Act as a flushing medium for the removal of the chips.

2.4 TITANIUM ALLOY WORKPIECE

The workpiece used in this research was Ti6Al4V, a popular material for medical instruments and aeronautic industries. This titanium alloy has high melting temperature (16048^{0}C) and low thermal conductivity (0.016 cal/s cm 8^{0}C). It can be classier as a difficult-to-cut material, not suitable for traditional machining. The specimen dimensions were diameter 25mm and thickness 6mm. In addition, the electrode material was copper tungsten with dimensions of diameter 5 mm and length 26mm.

2.5 TAGUCHI METHOD

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use (Wiley, 1991). An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence (S. Fraley, M. Oom, B. Terrien, and J. Z. Date, 2006).

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables. The Taguchi method has been criticized in the literature for its difficulty in accounting for interactions between parameters. Another limitation is that the Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study. Furthermore, since the Taguchi methods deal with designing quality rather than correcting for poor quality, they are applied most effectively at early stages of process development (UnitekMiyachi Group, (1999)).

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.

2.6. ORTHOGONAL ARRAY EXPERIMENT

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between factors parameters that need to be made to determine which level is better and specifically how much better it is. For example, a three-level factors parameter counts for two degrees of freedom. The degrees of freedom associated with interaction between two factors parameters are given by the product of the degrees of freedom for the two factors parameters. In the present study, the interaction between the cutting parameters is neglected. Therefore, there are six degrees of freedom owing to the three cutting parameters in turning operations.

Once the degrees of freedom required are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the factors parameters.

2.7 ANALYSIS OF VARIANCE

The purpose of the ANOVA is to investigate which of the factors parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the factors parameters and the error. First, the total sum of the squared deviations SS_T from the total mean of the S/N ratio η can be calculated as (T.R. Lin (2002)),

$$\begin{aligned} SS_{\mathrm{T}} &= \sum_{i=1}^{m}(\eta_i - \bar{\eta})^2 = \sum_{i=1}^{m}\eta_i^2 - \sum_{i=1}^{m}2\eta_i\bar{\eta} + \sum_{i=1}^{m}\bar{\eta}^2 \\ &= \sum_{i=1}^{m}\eta_i^2 - 2m\bar{\eta}^2 + m\bar{\eta}^2 = \sum_{i=1}^{m}\eta_i^2 - m\bar{\eta}^2 \\ &= \sum_{i=1}^{m}\eta_i^2 - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2 \end{aligned}$$

where$m$ is the number of experiments in the orthogonal array. The total sum of the squared deviations SS_{T} is decomposed into two sources: the sum of the squared deviations SS_{P} due to each factors parameter and the sum of the squared error SS_{e}. SS_{P} can be calculated as:

$$SS_{\mathrm{P}} = \sum_{j=1}^{t}\frac{(s\eta_i)^2}{t} - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2$$

where p represent one of the experiment parameters, j the level number of this parameter p, t the repetition of each level of the parameter p, $s\eta_j$ the sum of the S/N ratio involving this parameter p and level j.
The sum of squares from error parameters SS_{e} is

$$SS_{\mathrm{e}} = SS_{\mathrm{T}} - SS_{\mathrm{A}} - SS_{\mathrm{B}} - SS_{\mathrm{C}}$$

The total degrees of freedom is $D_{\mathrm{T}} = m - 1$, where the degrees of freedom of the tested parameter $D_{\mathrm{p}} = t - 1$. The variance of the parameter tested is $V_{\mathrm{P}} = SS_{\mathrm{P}}/D_{\mathrm{P}}$. Then, the F-value for each design parameter is simply the ratio of the mean of squares deviations to the mean of the squared error ($F_{\mathrm{P}} = V_{\mathrm{P}}/V_{\mathrm{e}}$). The corrected sum of squares S_{P} can be calculated as:

$$\widehat{S}_{\mathrm{P}} = SS_{\mathrm{P}} - D_{\mathrm{P}}V_{\mathrm{e}}$$

The percentage contribution ρ can be calculated as:

$$\rho = \frac{\widehat{S}_{\mathrm{P}}}{SS_{\mathrm{T}}}$$

Statistically, there is a tool called the *F*-test named after Fisher (R.A. Fisher Statistical methods for research worker Oliver & Boyd, (1925)) to see which factors parameters have a significant effect on the performance characteristic. In performing the *F*-test, the mean of the squared deviations SS_{m} due to each factors parameter needs to be calculated. The mean of the squared deviations SS_{m} is equal to the sum of the squared deviations SS_{d} divided by the number of degrees of freedom associated with the factors parameter. Then, the *F*-value for each factors parameter is simply a ratio of the mean of the squared deviations SS_{m} to the mean of the squared error SS_{e}. Usually the larger the *F*-value, the greater the effect on the performance characteristic due to the change of the factors parameter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe about the overall process of methodology in this project from beginning until end of the project. There are four main processes that start with experimental, collecting the data, result analysis and confirmation test. All the processes will be described in this chapter by following the chart. During this part, every information and data will be gathered together and concluded according to the objectives and scope of the project.

The method are basically refers to the design of experiment (DOE) methodology and the procedure. The DOE is not a simple step process since it require many procedure and steps to follow. Actually, a series which must follow certain sequence for the experiment to yield an improve understanding of the outcome or product.

3.1.1 Location Of Experiment

This project is to be conducted in Laboratory EDM machine and Laboratory Material of Faculty Mechanical Engineering, University Malaysia Pahang, Pekan.

3.2 FLOW CHART

Flow chart is an important method in order to make sure the project can be done on time. Based from the flow chart, the project started with the literature review on the project. Research was made through journals, webs, books and other related sources.

The design of experiment is conducted after all the information about the project is gathered. The required parameters need to be defined as a design factor. The experiment start after workpiece, electrode and machine setup was prepared. Then, collect the data and analyze it based on the constructed table attached in the appendices.

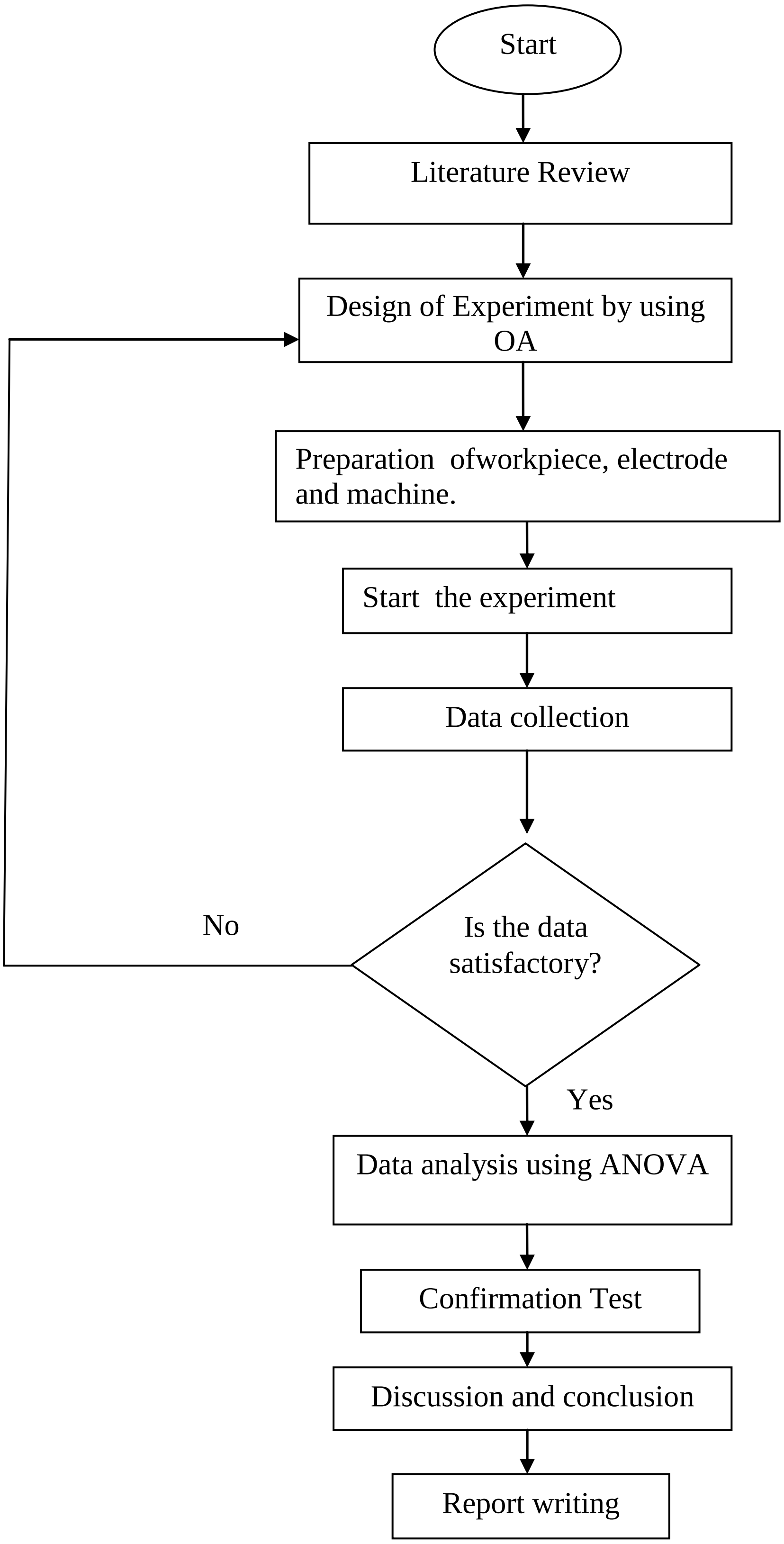


Figure 3.1 : Flow chart that outlines the steps undertaken.

3.2.1 Planning Of Experiment Using Taguchi Method

This experiment uses Taguchi method, which is very effective for determining the relationship between factors affecting the process and the output of the process here in machining characteristics optimization of the die-sinking EDM method experiment. This method is a powerful Design of Experiments tool, which provides a simple, efficient and systematic approach to determine optimal machining parameters. Compared to the conventional approach to experimentation, this method reduces drastically the number of experiments that are required to model the response functions. Traditional experimentation involves one-factor-at-a-time experiments, wherein one variable is changed while the rest are held constant. The major disadvantage of this strategy is that it fails to consider any possible interactions between the parameters. An interaction is the failure of one factor to produce the same effect on the response at different levels of another factor. It is also impossible to study all the factors and determine their main effects (i.e., the individual effects) in a single experiment. Taguchi technique overcomes all these drawbacks. The main effect is the average value of the response function at a particular level of a parameter. The effect of a factor level is the deviation it causes from the overall mean response. The Taguchi method is devised for process optimization and identification of optimal combinations of factors for given responses (Y.S Tarang, W.H Yang (1998)).

Taguchi method overcomes all these drawbacks. It has developed a method based on “Orthogonal Array” experiments which gives much improved quality for the experiment with “optimum settings” of control parameters. Thus the marriage Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi method. Orthogonal Array is a fundamental component in the statistical design of experiments and it is used for the construction and layouts of experiments. For example, a 3-level $\mathbf{L}_n(3^{n-1})$ orthogonal array is a saturated fractional factorial design that has n rows and $n - 1$ columns, where n is 18. Each row of such an orthogonal array corresponds to a combination of levels of the varying factors, which generates a run in the experiment.

Figure 3.2 below shows the steps involved in Taguchi Method for the Design of Experiment:-

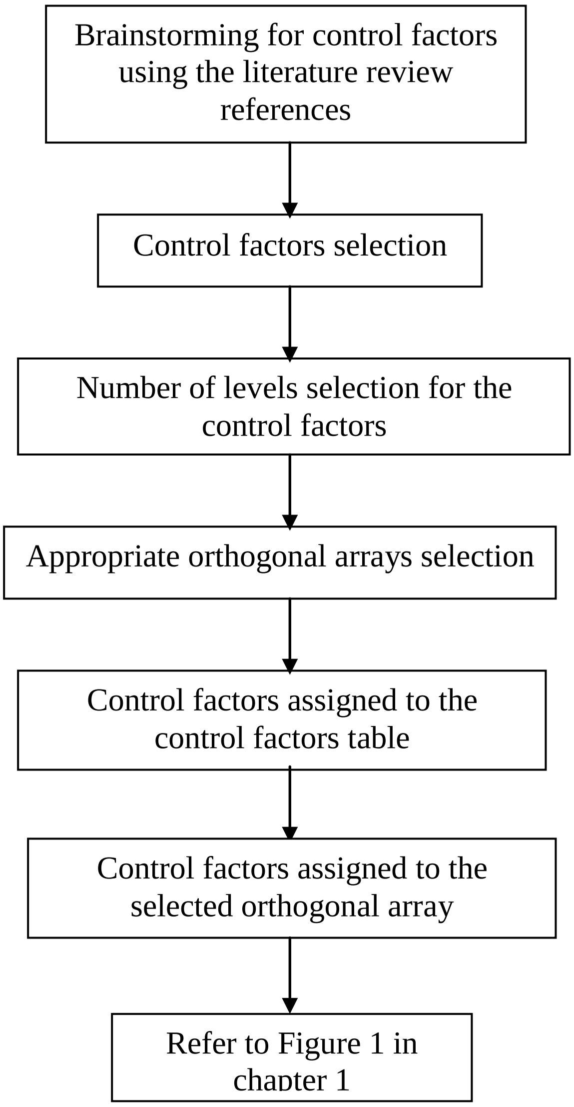


Figure 3.2 : Steps involved in Taguchi Method for The Design of Experiment

3.2.2 Brainstorming for control factors

Brainstorming is a technique in identifying the most influential factors in an experiment. In the Figure 8 shows the cause and effect diagram of control factors that most affect the machining characteristics optimization in die-sinking EDM method. The cause and effect diagram is a tool that can assist for brainstorming process. With the help from the literature review references too, the diagram has been successfully filled in order of achieving in high material removal rate (MRR), low electrode wear ratio (EWR) and low surface roughness (SR) machining characteristics.

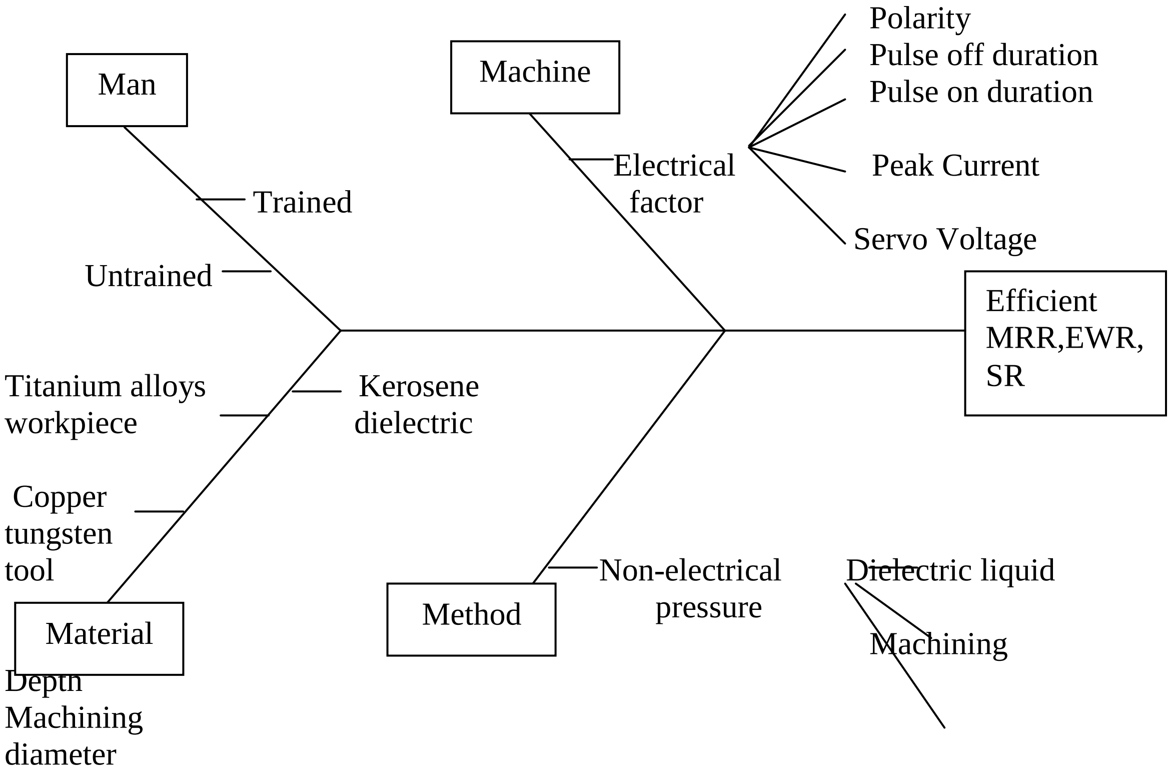


Figure 3.3 : Cause and Effect Diagram-Brainstorming for Process Parameters

3.3 RESEARCH DESIGN VARIABLES

The design variables are described into two main groups, which are response parameters and machining parameters.

3.3.1 Response Parameters

The response parameters include:
1. Material removal rate (MRR)
2. Electrode wear rate (EWR)
3. Surface Roughness (SR)

3.3.2 Machining Parameters

The parameters that are involved in this study are shown in Table 3.1.

Table 3.1 : Machining parameters

Variable	Set-up
Name of machine	AQ55L (ATC) Die-sinking EDM
Workpiece	Ti–6Al–4V (Ti-64) Block size : 25 x 6 mm
Tool electrode	Copper tungsten(∅5 mm)
Polarity	Positive and negative (EDM process)
Voltage (V)	80 - 160
P (current, A)	8 – 24
A (pulse on time, µs)	12.8 – 50
B (interval time, µs)	12.8 - 50
Dielectric Fluid	Kerosene
Dielectric liquid pressure	1.5 bar
Depth of hole	0.5mm

3.3.3 Workpiece material

The workpiece used in this project is Titanium Alloys Ti–6Al–4V which is a conductive material. This material also is a expensive material compare to others while the properties make it suitable for this project. The estimated size of the workpiece is 25 x 6 mm. Table 2 shown the properties.

Table 3.2: Titanium Alloys Ti–6Al–4V properties.

Work Materials	
Chemical composition	
Titanium Alloys	6.53% Al, 3.89% V, 0.035% Mo, 0.128% Fe, 0.02%Zr,0.024% Si, 0.05% C, 0.181% O
Density (kg/m^3)	4.4
Melting point (°C)	1650–1670
Modulus of elasticity (Gpa)	107–122 (20◦C) 105–111 (230◦C)
Poissons ratio	0.31
Specific heat capacity (J/(kg*K))	586. (20–570◦C)
Thermal conductivity (W/(m*K))	6.6 (20°C) 10.6 (315°C) 17.5 (650°C)
Coefficient of thermal expansion ($\times 10^{-6}$ K^{-1})	9.0 (0–100°C) 9.4 (20–425°C)

Source: P.J.Blau et al. (2003)

3.3.4 Electrode material

The electrode material used in this experiment is copper tungsten properties. The estimated size of the electrode used is 1.5 cm in diameter and 3.5 cm in length. The properties of the copper are listed in Table3.

Table 3.3: Copper Tungsten Properties

Electrode material properties	
Material	
Composition	75% Tungsten 25% Copper
Density (g/cm^3)	15.2
Melting point (^{0}C)	3500
Electrical resistivity (μΩ cm)	5.5
Hardness	HB 200

Source: S.H.Lee et al. (1999).

3.4 DESIGN OF EXPERIMENT

Based on OA method of DOE, an L_{18} (2^1 x 3^5) orthogonal arrays table with 18 rows (number of experiments), was selected for the experimentation (NicoloBelavendram, 2005). Experimental layout of L_{18} orthogonal array is shown in Appendix B1.

L_{18} (2^1 x 3^5) orthogonal array has a special property where two degree of freedom are taken up between a 2-level and 3-level factor. In general, the experimenter should seek the smallest orthogonal array for an experiment.

The use of the orthogonal array with the grey relational analysis to optimize the process includes the following steps (J.L. Lin et al., 2001):

1. Select the appropriate orthogonal array and assign the process parameters to the orthogonal array.
2. Conduct the experiments based on the arrangement of the orthogonal array.
3. Normalized the experimental results of electrode wear ratio, material removal rate and surface roughness.
4. Determination of optimum condition using response graph.
5. Analyze the experimental results by statistical analysis of variance (ANOVA) by using MINITAB software..
6. Select the optimal levels of process parameters.
7. Verify the optimal process parameters through the confirmation experiment.

The normalized experimental results for MRR which observes the higher the value, the better performance criteria. Meanwhile, EWR and SR observe the lower-the-better performance criteria. Larger normalized results correspond to the better performance and the best normalized result should be equal to 1.The normalized values are ranged between zero and one. The larger values yield better performance and the ideal value should be equal to one (M.A.Azmir et al., 2008).

3.4.1 Number of levels and appropriate Orthogonal Array selection

In the Table 3.4 shows the Standard Orthogonal Arrays table that has been used usually for most experiments cases. With the reference below, obviously the highlighted one-2-level and four-3-level L18 Orthogonal Array is the most appropriate level and standard orthogonal array selection for the experiment. This selection is best referred from the selected relation of five control factors before. Even though there have for five control factor, but this experiment have use for eight control factors because it have for one-2-level and four-3-level. So, L18 have been use for this experiment.

Table 3.4: Standard Orthogonal Arrays

Orthogonal Array	***No. Of Rows***	***Max No. Of Factors***	**Maximum Number of Columns at these levels**			
			2	**3**	**4**	**5**
L4	4	3	3	-	-	-
L8	8	7	7	-	-	-
L9	9	4	-	4	-	-
L12	12	11	11	-	-	-
L16	16	15	15	-	-	-
L16	16	5	-	-	4	-
L18	**18**	**8**	**1**	**7**	**-**	**-**
L25	25	6		-	-	6

3.4.2 Design factors selected

There are a large number of factors to consider within the EDM process, but in this work the level of the pulse off time, pulse on duration, peak current, workpiece polarity and servo voltage have only been taken into account as design factors. The reason why these five factors have been selected as design factors is that they are the most widespread and used amongst EDM researchers. Table 3.5 shows the level of experimentation in this project is three which are low, medium and high.

Table 3.5 : Control factorsand their respective levels

Factors	Description	Level 1	Level 2	Level 3	Units
A	Polarity, P	Workpiece (+) Tool (-)	Workpiece (-) Tool (+)	-	Positive(+) Negative (-)
B	Peak Current (A)	2	16	30	Ampere
C	Pulse-on-duration, µon	10	205	400	microsec
D	Pulse-off-duration,µoff	50	175	300	microsec
E	Servo Voltage	40	70	90	V

3.4.3 Method for Sample Preparations

Before experiment starts, total 18 numbers of Titanium Alloys Ti–6Al–4V workpieces measured of diameter 25mm and thickness 6mm with even and clean surface are desired for the experiment. Beside that, total nine numbers of copper tungsten electrode measured of diameter 5 mm, length 26mm also have been cut for nine sample. Several methods are used to discover them and the method are:-

For workpiece :

1. Cutting off using EDM wire cut, the standard manufactured Titanium Alloys Ti–6Al–4V measured of 1200 mm (length) x 25 mm (diameter) into smaller bar dimension measured of 6 mm (length) x 25 mm (diameter).
2. Next, clean the cut titanium alloys Ti–6Al–4V using soap water.
3. Finally, cleaned titanium alloys Ti–6Al–4V are ready for the experiment.

For electrode :

1. Cutting off using abrasive metal cutter, the standard manufactured copper tungsten measured of 900 mm (length) x 5 mm (diameter) into smaller bar dimension measured of 26 mm (length) x 5 mm (diameter).
2. Next, clean the cut copper using sand paper. Make sure the surface that will be use is flat and less roughness.
3. Finally, cleaned copper tungsten are ready for the experiment.

3.4.4 Machined Samples

Table 15 shows the workpiece and electrode that have been used for this 18 experiments.

Figure 3.4 :Sample for workpiece

Figure 3.5: Sample for electrode

3.4.5 Use of the EDM Machine Equipment

The machine used in this study is a AQ55L (ATC) Die-sinking EDM. This machine is place in laboratory EDM machine of Faculty Mechanical Engineering, University Malaysia Pahang, Pekan. The picture of the Die-sinking EDM is shown in Figure 3.6.

Figure 3.6 :AQ55L (ATC) Die-sinking EDM

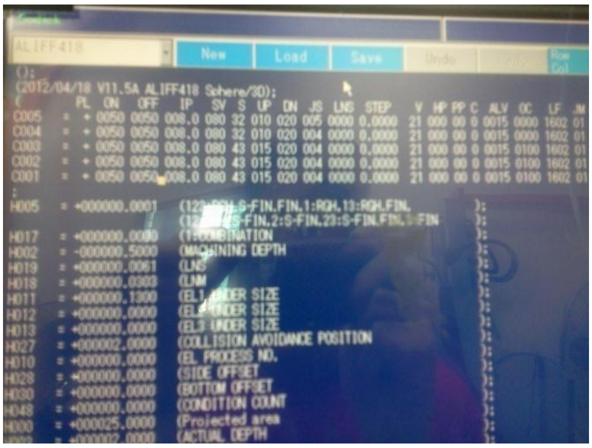
The AQ55L (ATC) Die-sinking EDM. Electrical have the several basic components are:-

a) Axis designation and direction

The electrode holder could moved in X, Y and Z axis and traveling for each axis was defined using [+] and [-] direction.

b) Controller unit

Figure 3.7 shows the controller unit of the EDM machine



```
():
(2012/04/18 V11.5A ALIFF418 Sphere/3D):
(       PL  ON   OFF  IP    SV  S  UP  DN  JS  LNS  STEP    V  HP  PP C ALV  OC   LF   JM
C005  =  + 0050 0050 008.0 080 32 010 020 005 0000 0.0000  21 000 00 0 0015 0000 1602 01
C004  =  + 0050 0050 008.0 080 32 010 020 004 0000 0.0000  21 000 00 0 0015 0000 1602 01
C003  =  + 0050 0050 008.0 080 43 015 020 004 0000 0.0000  21 000 00 0 0015 0100 1602 01
C002  =  + 0050 0050 008.0 080 43 015 020 004 0000 0.0000  21 000 00 0 0015 0100 1602 01
C001  =  + 0050 0050 008.0 080 43 015 020 004 0000 0.0000  21 000 00 0 0015 0100 1602 01
:
H005  = +000000.0001   (122:[illegible]S-FIN.FIN,1:RGH,13:RGH.FIN,          ):
                       (12[illegible]S-FIN,2:S-FIN,23:S-FIN.FIN,[illegible]FIN  ):
H017  = +000000.0000   (1:COMBINATION                                       ):
H002  = -000000.5000   (MACHINING DEPTH                                     ):
H019  = +000000.0061   (LNS                                                 ):
H018  = +000000.0003   (LNM                                                 ):
H011  = +000000.1300   (EL1 UNDER SIZE                                      ):
H012  = +000000.0000   (EL2 UNDER SIZE                                      ):
H013  = +000000.0000   (EL3 UNDER SIZE                                      ):
H027  = +000002.0000   (COLLISION AVOIDANCE POSITION                        ):
H010  = +000000.0000   (EL PROCESS NO.                                      ):
H028  = +000000.0000   (SIDE OFFSET                                         ):
H030  = +000000.0000   (BOTTOM OFFSET                                       ):
H048  = +000000.0000   (CONDITION COUNT                                     ):
H000  = +000025.0000   (Projected area                                      ):
```

Figure 3.7 :EDM Controller unit

c) Machining tank

Consist of machining bath, fluid level control section and fluid pressure control section.

d) Electrode holder

Figure 3.8 shows the electrode holder that was used to hold the electrode.

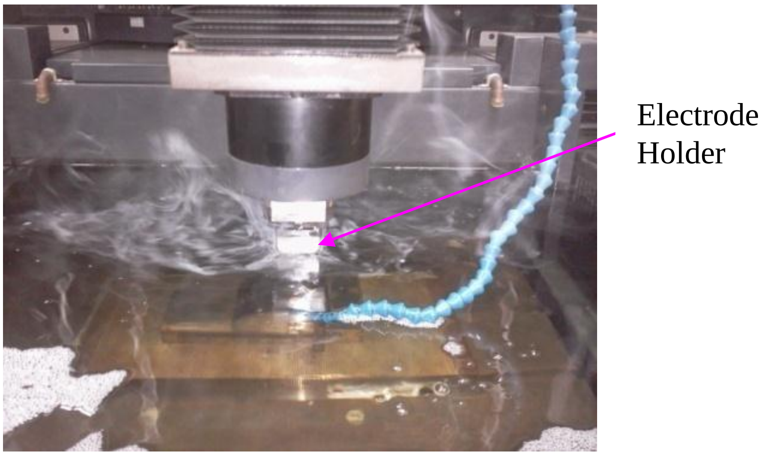


Figure 3.8 : Electrode Holder

3.5 DATA COLLECTION

3.5.1 Weight Loss

The weight loss of the workpiece and tool electrode would be taken before and after each experiment. The measurement is taken using the weighing machine shown in Figure 3.9:-

Figure 3.9 : Weighing Machine

3.5.2 Surface Roughness

The Surface Roughness (SR) of the machined workpiece is measure using Perthometer Surface Roughness Measuring Machine. 2 measurement was taken per workpiece after experiment. Figure 3.10 shows the respective machine used for this purpose.

Figure 3.10 : Surface Roughness Measuring Machine

3.5.3 Machining Characteristics Calculation

i) Material Removal Rate (MRR)

The weighing of the initial workpiece mass before machining minus the workpiece mass loss with the machining time taken will represent the Material Removal Rate (MRR) of the workpiece.

The Material Removal Rate (MRR) is expressed as the workpiece removal weight (WRW) under a period of machining time in minute (T), that is:-

$$\text{MRR (g/min)} = \frac{WRW}{T} \qquad (1)$$

ii) Electrode Wear Ratio (EWR)

The weighing of the pipe tool electrode mass loss represents the Electrode Wear Ratio (EWR). The electrode wear ratio (EWR) is defined by the ratio of the electrode wear weight (EWW) to the workpiece removal weight (WRW) and usually expressed as a percentage, which is:-

$$\text{EWR (\%)} = \frac{EWW}{WRW} \text{ x } 100 \qquad (2)$$

iii) Surface Roughness (SR)

A Perthometer measured the machined surface roughness. The center-line average surface roughness R_a is measured to quantitatively evaluate how EDM parameters affect the surface finish.

3.5.4 Data Analysis

The experiment data i.e. the machining time obtained from EDM experiment will be used to calculate the machining characteristics i.e Material Removal Rate (MRR) and Surface Roughness (SR).

3.5.5 Optimum Condition Using Response Graph

The optimum condition for each machining characteristics i.e. MRR, EWR and SR is determine using response graph. The quality characteristics of each machining characteristics i.e. material removal rate (MRR) is larger-the-better, the optimum condition for this machining characteristic is at the maximum point for each factor on the material removal rate response graph. Figure 3.11 below shows the example of the response graph for MRR.

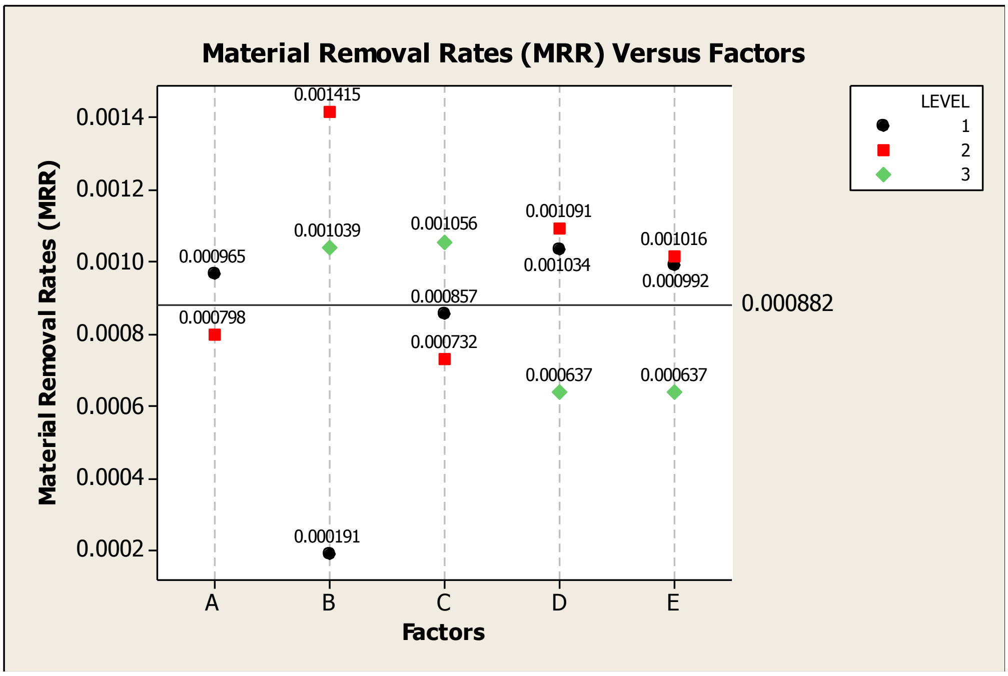


Figure 3.11 : Response Graph of Experiment Sampling for Material Removal Rate (MRR)

These optimum condition could be simplified as A1B2C3D1E2. Response graph is created base on the response table values. Table 3.6 below shows the example of the response table involved.

Table 3.6 : Response Table MRR

Parameter	A	B	C	D	E
Level 1	0.000965	0.000191	0.000857	0.001034	0.000992
Level 2	0.000798	0.001415	0.000732	0.001091	0.001016
Level 3	*	0.001039	0.001056	0.000637	0.000637

The response table is created base on the calculation of the average of the average figure (bolded) on the orthogonal array table 3.7 below. Let say for factor A level 1, the average values of the average figure from experiment 1 until 9, the average value of the average values (bolded) is calculated.

Table 3.7 : Orthogonal Array table

Exp	A	B	C	D	E	Average values for		
						MRR (g/min)	EWR (%)	SR (μm)
1	+	2	10	50	40	**0.000477**	143.7063	1.262
2	+	2	205	175	70	**0.000240**	13.4571	1.573
3	+	2	400	300	90	**0.000024**	90.1408	1.284
4	+	16	10	50	70	**0.001805**	22.9917	2.470
5	+	16	205	175	90	**0.000470**	29.7872	2.953
6	+	16	400	300	40	**0.002165**	35.1039	2.358
7	+	30	10	175	40	**0.000687**	25.9709	3.215
8	+	30	205	300	70	**0.001437**	3.7123	2.956
9	+	30	400	50	90	**0.001377**	15.9806	2.590
10	-	2	10	300	90	**0.000001**	297.222	1.115
11	-	2	205	50	40	**0.000280**	51.6129	1.783
12	-	2	400	175	70	**0.000124**	39.9463	1.934
13	-	16	10	175	90	**0.001237**	14.0162	2.462
14	-	16	205	300	40	**0.001253**	34.0426	2.859
15	-	16	400	50	70	**0.001557**	34.9036	2.823
16	-	30	10	300	70	**0.000933**	12.8571	3.059
17	-	30	205	175	90	**0.000710**	14.5540	3.066
18	-	30	400	50	40	**0.001091**	13.8493	2.956

3.6 ANALYSIS OF VARIANCE (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which machining parameters significantly affect the performance characteristic. In this study, MINITAB software was used to construct ANOVA table.

3.7 CONFIRMATION TEST

The confirmation tests were conducted by selecting the optimum combinations of machining factors. These confirmation tests were used to predict and verify the improvement in the quality characteristics for machining of mild steel AISI 1020 with respect to the chosen initial parameters setting.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter aim to explain the analysis of the project. This analysis will show the effect of the workpiece polarity, pulse off time, pulse on time, peak current, and servo voltage. This chapter represents the results and analysis data for 3 machining characteristics i.e. MRR, EWR and SR obtained from laboratory experiments. The analysis had done using ANOVA. Full result of the experiment and analysis will show in this chapter.

4.2 DATA RESULT

Table 4.1 shows the control factors used for the experiment. Total of 18 experiments were executed for each machining characteristics. Table for machining characteristic data were used for calculation the machining characteristic data. Orthogonal array table were used for selection of machining factors and levels before experiment starts. To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be recognized. The degrees of freedom are defined as the number of comparisons between machining parameters that need to be made to determine which level is better to conduct. In this study, an L18 orthogonal array is used because it has 17 degrees of freedom greater than 11 degrees of freedom in the selected machining parameters.

Table 4.1 : Control factors

Factors	Description	Level 1	Level 2	Level 3	Units
A	Polarity, P	Workpiece (+) Tool (-)	Workpiece (-) Tool (+)	- Positive(+) Negative (-)	
B	Peak Current (A)	2	16	30	Ampere
C	Pulse-on-duration, µ on	10	205	400	microsec
D	Pulse-off-duration, µoff	50	175	300	microsec
E	Servo Voltage	40	70	90	V

4.2.1 Observed Values of MRR, EWR and SR Analysis

Table 4.2 below shows the list of average values for 3 machining characteristics i.e. MRR, EWR and SR referred from the orthogonal array that has eight columns and 18 rows and it can handle one two-level machining parameter and four three-level machining parameters at most. Each machining parameter is assigned to a column and 18 machining parameter combinations are required. Therefore, only 18 experiments are needed to study the entire machining parameter space using the L18 orthogonal array. The experimental result is shown in Table 4.2.

Table 4.2 : Result of Experiment

Exp	A	B	C	D	E	Average values for		
						MRR (g/min)	EWR (%)	SR (µm)

1	+	2	10	50	40	0.000477	143.7063	1.262
2	+	2	205	175	70	0.000240	13.4571	1.573
3	+	2	400	300	90	0.000024	90.1408	1.284
4	+	16	10	50	70	0.001805	22.9917	2.470
5	+	16	205	175	90	0.000470	29.7872	2.953
6	+	16	400	300	40	0.002165	35.1039	2.358
7	+	30	10	175	40	0.000687	25.9709	3.215
8	+	30	205	300	70	0.001437	3.7123	2.956
9	+	30	400	50	90	0.001377	15.9806	2.590
10	-	2	10	300	90	0.000001	297.222	1.115
11	-	2	205	50	40	0.000280	51.6129	1.783
12	-	2	400	175	70	0.000124	39.9463	1.934
13	-	16	10	175	90	0.001237	14.0162	2.462
14	-	16	205	300	40	0.001253	34.0426	2.859
15	-	16	400	50	70	0.001557	34.9036	2.823
16	-	30	10	300	70	0.000933	12.8571	3.059
17	-	30	205	175	90	0.000710	14.5540	3.066
18	-	30	400	50	40	0.001091	13.8493	2.956

4.3 DETERMINATION OF OPTIMUM CONDITION USING RESPONSE GRAPH

To get the optimum parameters of every machining, the condition of every machining characteristic must higher material removal rate (MRR), lower Electrode Wear Ratio (EWR) and lower Surface Roughness (SR). By using Taguchi method, the observed values of MRR, EWR and SR were set to maximum, minimum and minimum, respectively. The maximum observed values tells the quality characteristics is larger-the-better and minimum observed values tells the quality characteristics is lower-the-better

4.3.1 Optimum Condition for MRR

Higher MRR is required for only rough machining. Table 6 show the response table of MRR. At the below of this table 4.3, it show the figure 4.1 about the response graph used to determine the optimum condition of the MRR machining characteristic.

Table 4.3 : Response Table MRR

Parameter	A	B	C	D	E
Level 1	0.000965	0.000191	0.000857	0.001034	0.000992
Level 2	0.000798	0.001415	0.000732	0.001091	0.001016
Level 3	*	0.001039	0.001056	0.000637	0.000637

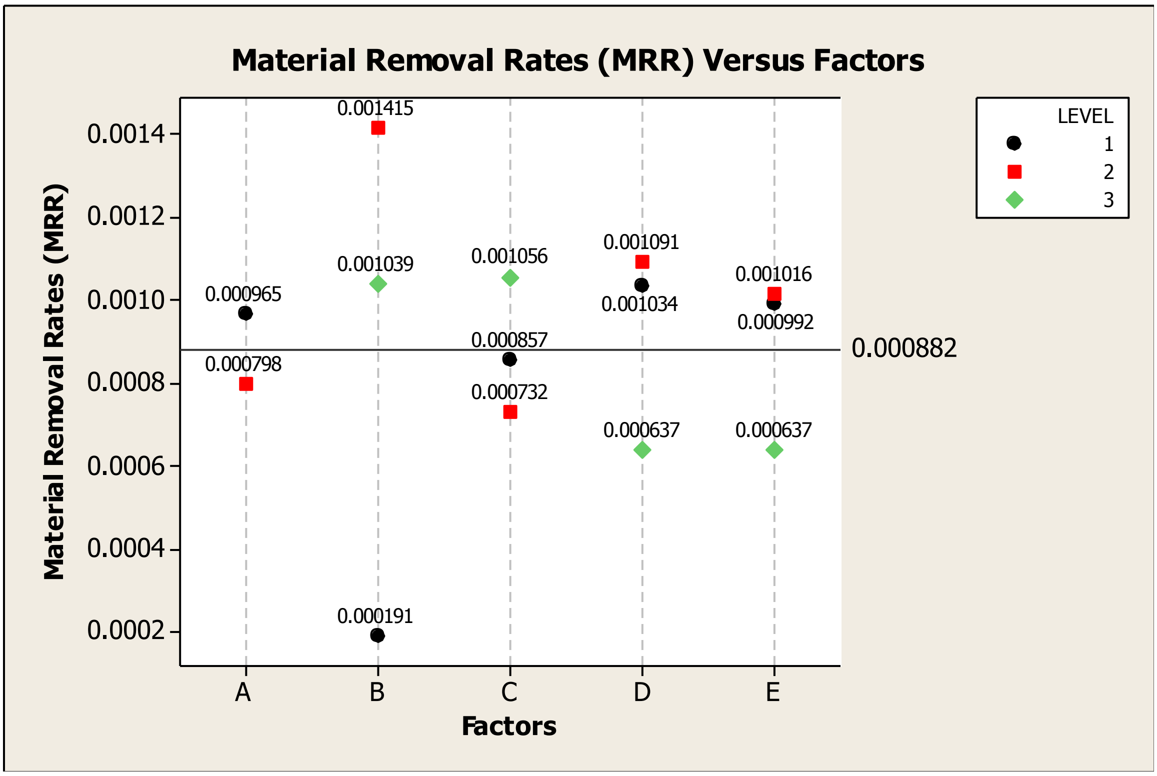


Figure 4.1 : Graph Of Response Table For MRR

This graph have been done by using MINITAB software. Its show the material removal rates versus five difference factors in three level. The reference point is 0.000882 and its taken from the average of material removal rates result. The optimum condition for maximum material removal rate are positive polarity (workpiece positive and tool negative), 16 Ampere of peak current 400 microseconds of pulse on duration, 175 microseconds of pulse off duration, 70 volt of servo voltage. These optimum condition could be simplified as A1B2C3D1E2.

4.3.2 Optimum Condition for EWR

`The EWR is an essential value owing to its effect on dimensional accuracy and the shaped produced. Thus, the lower EWR was required for intermediate finishing. Table 4.4 shows the response table of EWR and the figure 4.2 below shows the response graph used to determine the optimum condition of the EWR machining characteristic.

Table 4.4 : Response Table EWR

Parameter	A	B	C	D	E
Level 1	43.31676	106.0142	86.12737	47.29152	50.71432
Level 2	57.00044	28.4742	24.52768	22.83783	50.71432
Level 3	*	14.48737	38.32075	78.84645	76.95013

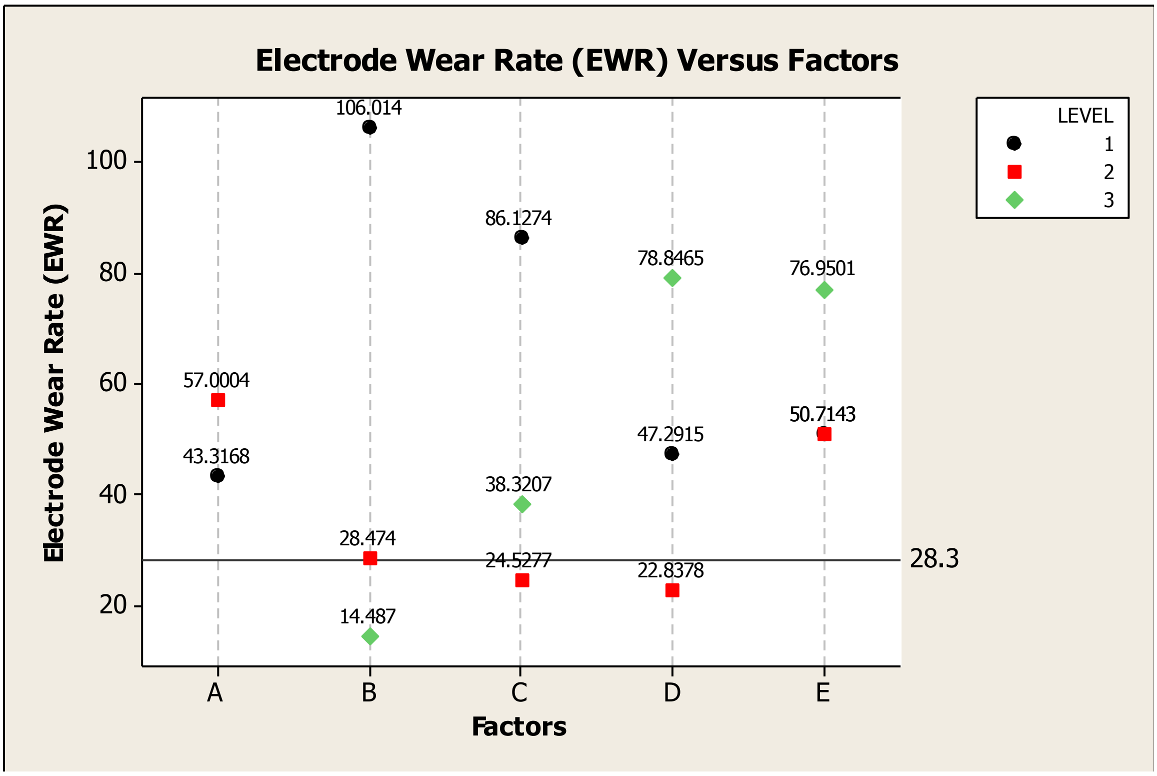


Figure 4.2 : Graph Of Response Table For EWR

The reference point is 28.3% and its taken from the average of electrode wear rates result. From this graph, the optimum condition for EWR are; negative polarity, 30 Ampere of peak current, 205 microseconds of pulse on duration, 175 microseconds of pulse off duration, 70 volt of servo voltage. These optimum condition could be simplified as A1B3C2D2E2.

\

4.3.3 Optimum Condition for SR

Table 4.5 show the surface roughness versus five difference factors in three level. The reference point is 2.373 and its taken from the average of surface roughness result. Surface roughnessis the measure if the finer surface irregularities in the surface texture To get the optimize condition, the lower SR was required for fine finishing. Figure 4.3 below shows the response graph for SR.

Table 4.5 : Response Table SR

Parameter	A	B	C	D	E
Level 1	2.295667	1.491833	2.263833	2.332333	2.4055
Level 2	2.450778	2.654167	2.531667	2.5155	2.4691
Level 3	*	2.973667	2.324167	2.271833	2.2450

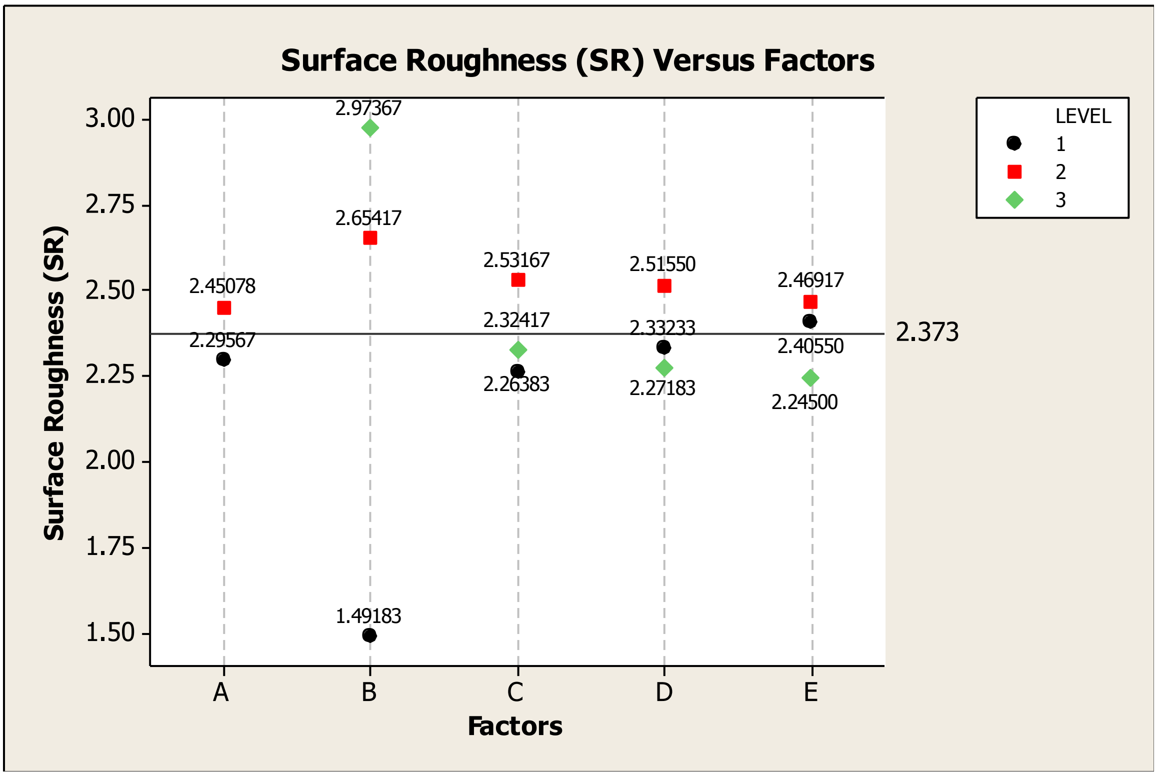


Figure 4.3 : Graph Of Response Table For SR

The reference point is 2.373 µm and its taken from the average of surface roughness rates result. From this graph, the optimum condition for SR are positive polarity(workpiece positive and tool negative), 2 Ampere of peak current, 10 microseconds of pulse on duration, 300 microseconds of pulse off duration, 90 volt of servo voltage. These optimum statement could be simplified as A1B1C1D3E3.

4.4 DETERMINATION OF SIGNIFICANT FACTOR USING ANALYSIS OF VARIANCE (ANOVA)

The present study used ANOVA to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters. An ANOVA (analysis of variance) table is commonly used to summarize the experimental results. The results from the Table 5 were then input to the MINITAB software for further analysis. This software will give the summary about the experiment. The observed values were related to five parameters and three levels which were related to the EDM working conditions. The table concludes information of analysis of variance and case statistics for further interpretation. Table 9,table 10 and table 11 shows the ANOVA table for MRR, EWR and SR after transformation from Microsoft excel to Minitab software. Tables 9, 10 and 11 showed the ANOVA data lists for each of the machining characteristics; MRR, EWR and SR. Each of the data was calculated using ANOVA formulas as attached in the appendix section.

Significant factors in the ANOVA data list of p value were categorized into two levels, i.e. the most significant and significant. If the value of p is below 0.05, it means that it is the most significant parameter that most influence for that experiment and if it higher than 0.05, it not the significant parameters for this experiment.

Table 4.6 : Analysis of Variance (ANOVA) for MRR

Factor	Type	Levels	Values
Polarity	fixed	2	-, +
Peak Current	fixed	3	2, 16, 30
Pulse On duration	fixed	3	10, 205, 400
Pulse Of duration	fixed	3	50, 175, 300
Servo Voltage	fixed	3	40, 70, 90

Analysis of Variance for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution(%)
Polarity	1	0.0000001	0.0000001	0.0000001	1.02	0.342	1.41
Peak Current	2	0.0000047	0.0000047	0.0000024	19.30	0.001**	66.20
Pulse On duration	2	0.0000003	0.0000001	0.0000001	0.45	0.654	1.41
Pulse Off duration	2	0.0000006	0.0000004	0.0000002	1.64	0.254*	5.63
Servo Voltage	2	0.0000003	0.0000003	0.0000002	1.24	0.341	4.23
Error	8	0.0000010	0.0000010	0.0000001			14.08
Total	17	0.0000071					

** Most significant factor

* Significant factor

Table 4.6 shows the ANOVA table that have been achieves from MINITAB software for the material removal rates between five sources, where now the total number of degrees of freedom is equal to 17.The ANOVA table partitions the variability in MRR into separate pieces for each of the sources. It then tests the statistical significance of each effect by comparing the mean square against an estimate of the experimental error. This ways can predict what type of the parameter that will give more significant to the product. The hypothesis was as follows :

Polarity, peak current, pulse on duration, pulse off duration and servo voltage gives significant result to the optimization parameter. In this case, peak current have P-values less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level. The P- value of polarity is 0.342, pulse on duration is 0.654 pulse off duration is 0.254 and servo voltage is 0.341 are not give significant because they have P-values more than 0.05. So for this experiment to analyze about material removal rates, peak current have give the big effect to the experiment.

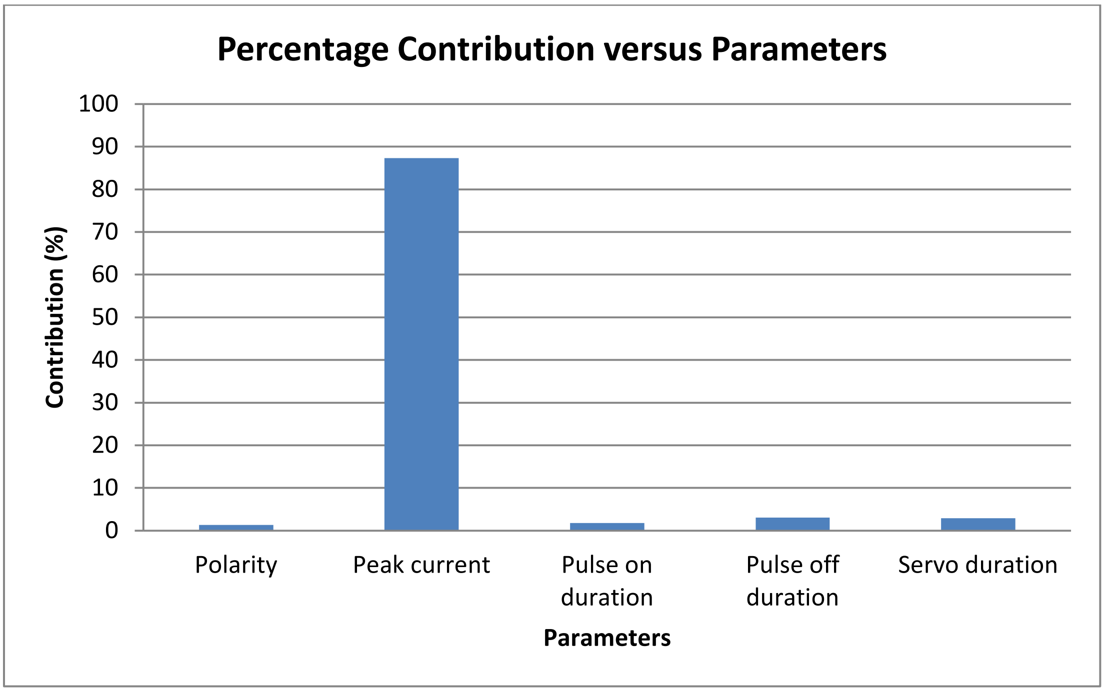


Figure 4.4 : Graph percentage contribution versus parameters

Based on the graph above, the highest percentage contribution was parameter peak current with the value of 66.20% and the lowest percentage contribution was parameter polarity and pulse on duration with 1.41%. Higher percentage contribution determine the most significant parameter to the product.

Table 4.7 : Analysis of Variance (ANOVA) for EWR

Factor	Type	Levels	Values
Polarity	fixed	2	-, +
Peak Current	fixed	3	2, 16, 30
Pulse On duration	fixed	3	10, 205, 400
Pulse Of duration	fixed	3	50, 175, 300
Servo Voltage	fixed	3	40, 70, 90

Analysis of Variance for EWR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution(%)
Polarity	1	970	970	970	0.37	0.561	1.16
Peak Current	2	29171	29171	14585	5.52	0.031**	34.77
Pulse On duration	2	12540	11977	5988	2.26	0.166*	14.27
Pulse Off duration	2	8967	10771	5386	2.04	0.193	12.84
Servo Voltage	2	11101	11101	5551	2.10	0.185	13.23
Error	8	21156	21156	2644			25.21
Total	17	83905					

** Most significant factor

* Significant factor

For analysis of variance (ANOVA) for EWR, polarity, peak current, pulse on duration, pulse off duration and servo voltage gives significant result to the optimization parameter. In this case, P-value for peak current is 0.031 that also less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level. The P- value of polarity is 0.561, pulse on duration is 0.166 , pulse off duration is 0.193 and servo voltage is 0.185 are not give significant because they have P-values more than 0.05. So for this experiment that have to analyze about electrode wear rates, peak current have give the big effect to the experiment.Peak current is the most significant value.

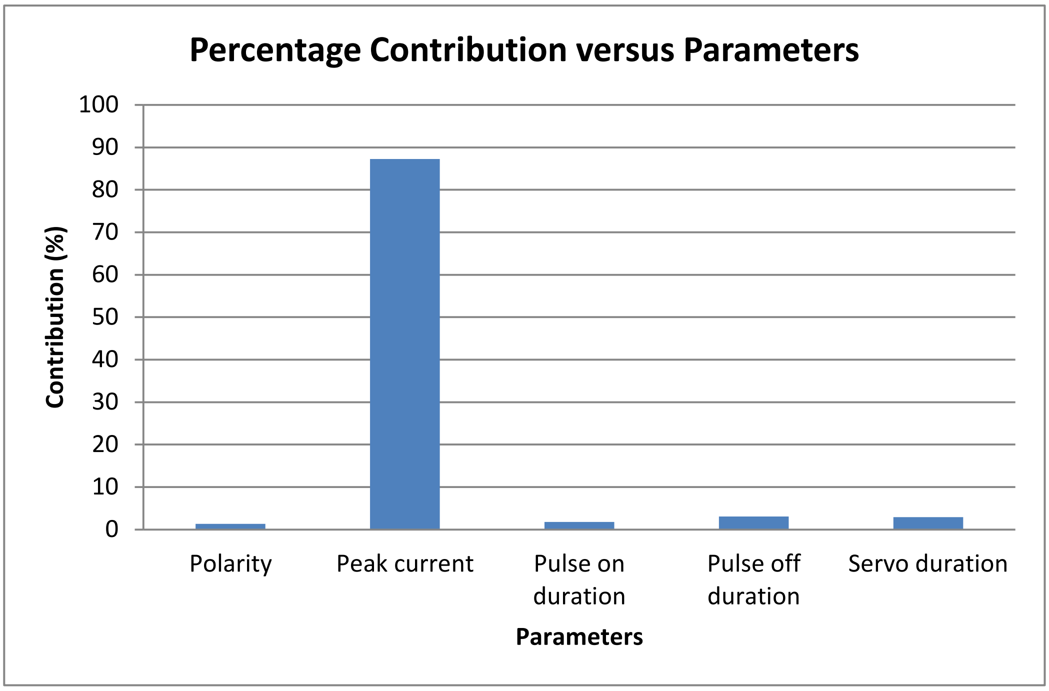


Figure 4.5 : Graph percentage contribution versus parameters

Based on the graph above, the highest percentage contribution was parameter peak current with the value of 34.77% and the lowest percentage contribution was parameter polarity with 1.16%. Higher percentage contribution determine the most significant parameter to the product.

Table 4.8 : Analysis of Variance (ANOVA) for SR

Factor	Type	Levels	Values
Polarity	fixed	2	-, +
Peak Current	fixed	3	2, 16, 30
Pulse On duration	fixed	3	10, 205, 400
Pulse Of duration	fixed	3	50, 175, 300
Servo Voltage	fixed	3	40, 70, 90

Analysis of Variance for SR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution(%)
Polarity	1	0.10827	0.10827	0.10827	2.83	0.131	1.29
Peak Current	2	7.29786	7.29786	3.64893	95.23	0.000**	87.26
Pulse On duration	2	0.23686	0.14549	0.07275	1.90	0.211	1.74
Pulse Off duration	2	0.16913	0.25330	0.12665	3.31	0.090*	3.03
Servo Voltage	2	0.24430	0.24430	0.12215	3.19	0.096	2.92
Error	8	0.30654	0.30654	0.03832			3.67
Total	17	8.36295					

** Most significant factor

* Significant factor

For analysis of variance (ANOVA) for surface roughness (SR), polarity, peak current, pulse on duration, pulse off duration and servo voltage gives significant result to the optimization parameter. In this case, P-value for peak current is 0.000003. This software only can give in three decimal places for every reading. That why the result shows only 0.000. P-value for peak current also less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level. The P- value of polarity is 0.131, pulse on duration is 0.211 , pulse off duration is 0.90 and servo voltage is 0.096 are not give significant because they have P-values more than 0.05. So for this experiment that have to analyze about surface roughness (SR), peak current have give the big effect to the experiment. Peak current is the most significant value.

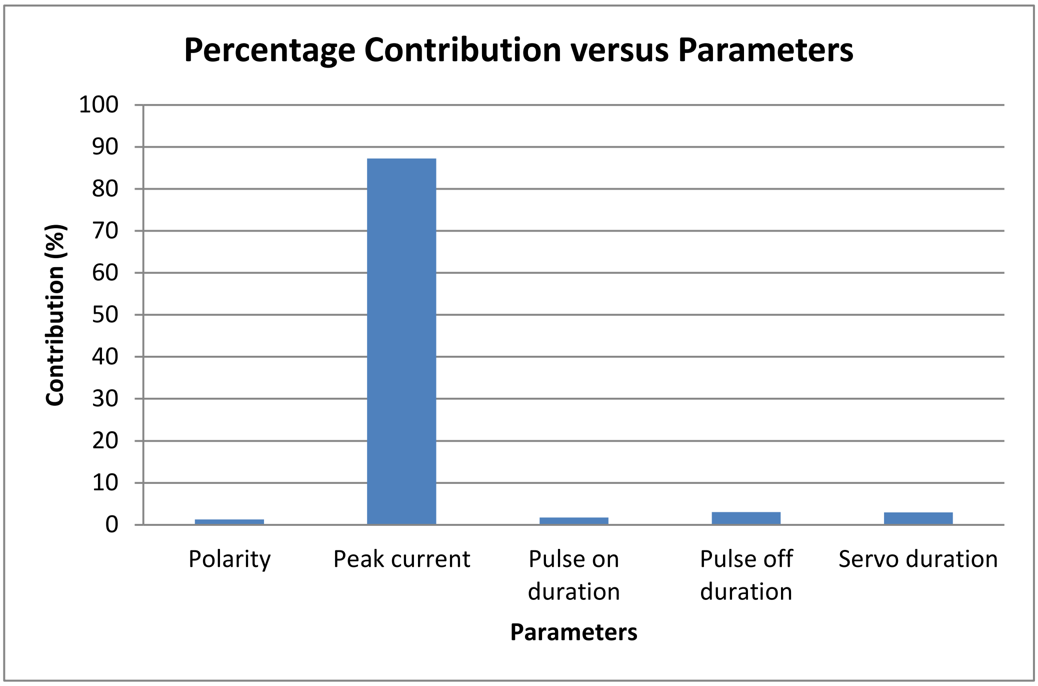


Figure 4.6 : Graph percentage contribution versus parameters

Based on the graph above, the highest percentage contribution was parameter B with the value of 87.29% and the lowest percentage contribution was parameter A with 1.29%. Higher percentage contribution determine the most significant parameter to the product.

4.5 CONFIRMATION EXPERIMENT

Once the optimal level of the process parameters has been determined, the final step is to predict and verify the improvement of the responses using the optimal level of process parameters. The optimum parameters is take from response table analysis. A confirmation experiment for MRR will be run according to the optimized factor levels for MRR (factors and levels of A1, B2, C3, D2, E2).
Below is the calculation for predict confirmation test.

1. Optimum MRR : A1B2C3D2E2

First significant parameters : B2 (Peak current) = 0.001415A
Second significant parameters : A1 (Polarity) = 0.000965
Third significant parameters : C3 (Pulse on duration) = 0.001056 τ on
$m_{mrr\,=}$ 0.000882

PV = m + (B3 – m) + (C2 – m) + (E3 – m)
= 0.000882 + (0.001415-0.000882) + (0.000965 – 0.000882) + (0.001056-0.000882)
= 0.001672

2. Optimum EWR : A1B3C2D2E2

First significant parameters : B3 (Peak current) = 14.48737A
Second significant parameters : C2 (Pulse on duration) = 24.52768 τ on
Third significant parameters : E2 (Servo Voltage) = 50.71432V
$M_{ewr\,=}$ 28.3

PV = m + (B3 – m) + (C2 – m) + (E3 – m)
= 28.3 + (14.48737-28.3) + (24.52768 – 28.3) + (50.71432-28.3)
= 22.4142

3. **Optimum SR : A1B3C2D2E2**

First significant parameters : B3 (Peak current) = 2.973667A
Second significant parameters : D2 (Pulse of duration) = 2.5155 τ on
Third significant parameters : E2 (Servo Voltage) = 2.469167V
$m_{sr} =$ 2.373222

PV = m + (B3 – m) + (D2 – m) + (E2 – m)
= 2.373222 + (2.973667-2.373222) + (2.5155– 2.373222) + (2.469167 - 2.373222)
= 3.2118

4.5.1 Data for MRR

Table 4.9 : Confirmation Experiment Data for MRR

Sample	Initial Weight, Wpi (g)	Final weight, Wpf (g)	Machine time, T (min)	MRR, (g/min)	MRR
1	14.31	14.27	25	0.028628	$^{0.0431}/_{25}$

4.5.2 Data for EWR

For EWR, by using optimized factors of A1, B3, C2, D2, E2. The table 4.10 below shows the confirmation experiment data.

Table 4.10 : Confirmation Experiment Data for EWR

Sample	Initial Weight, Wei (g)	Final weight, Wef (g)	MRR	EWR, $\frac{Wei - Wef}{Wp_i - Wp_f} \times 100$	EWR
1	7.6231	7.6215	0.001724	$^{0.0016}/_{0.001724}$ X 100	0.9281

4.5.3 Data for SR

Table 4.11 : Confirmation Experiment Data for SR

Sample	Ra (1)	Ra (2)	Ra (average)'
1	3.310	3.313	3.312

4.6 CONFIDENCE INTERVAL, CI

In statistics, a confidence interval (CI) is a particular kind of interval estimate of a population parameter and is used to indicate the reliability of an estimate. It is an observed interval (i.e. it is calculated from the observations), in principle different from sample to sample, that frequently includes the parameter of interest, if the experiment is repeated. How frequently the observed interval contains the parameter is determined by the confidence level.

4.6.1 Data for MRR

The sum of difference between predicted value and confirmation value is being calculated using the formula below:-

$y_{predicted} = 0.001672$; $y_{confirmation} = 0.001724$

$$CI = 100 - \left[\frac{\Delta y}{y_{predicted}} \times 100 \right] = 100 - \left[\frac{0.001724 - 0.001672}{0.001672} \times 100 \right] = 96.89\ \%$$

4.6.2 Data for EWR

$y_{predicted} = 22.4142$; $y_{confirmation} = 0.9281$

$$CI = 100 - \left[\frac{\Delta y}{y_{predicted}} \times 100 \right] = 100 - \left[\frac{0.9281 - 22.4142}{22.4142} \times 100 \right] = 195.86\%$$

4.6.3 Data for SR

$y_{\text{predicted}} = 3.212$; $y_{\text{confirmation}} = 3.312$

$$CI = 100 - \left[\frac{\Delta y}{y_{predicted}} \times 100 \right] = 100 - \left[\frac{3.312 - 3.212}{3.212} \times 100 \right] = 96.87\ \%$$

For machining characteristics for MRR and SR the sum of difference between the predicted value (PV) and confirmation sampling data is less than 10 %. This means $y_{\text{predicted}}$is quite similar to $y_{\text{confirmation}}$ for less than 10 % for MRR and SR. But for EWR, it value is so high than 100%. This is because, when doing the experiment, it maybe occur current surging or current dip. It means, when doing the experiment, we left the workpiece until its finish without observe what happen to that material. So, from ours result, experiment one and three get higher EWR. In theory, the interaction effects between factors are negligible. The experiment is reproducible only for factors MRR and SR.

4.7 MOST SIGNIFICANT FACTOR – PEAK CURRENT

In this experiment, peak current is the maximum amount of current which an output is capable of sourcing for brief periods of time that measured in units of amperage. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current.

Material Removal Rate (MRR)

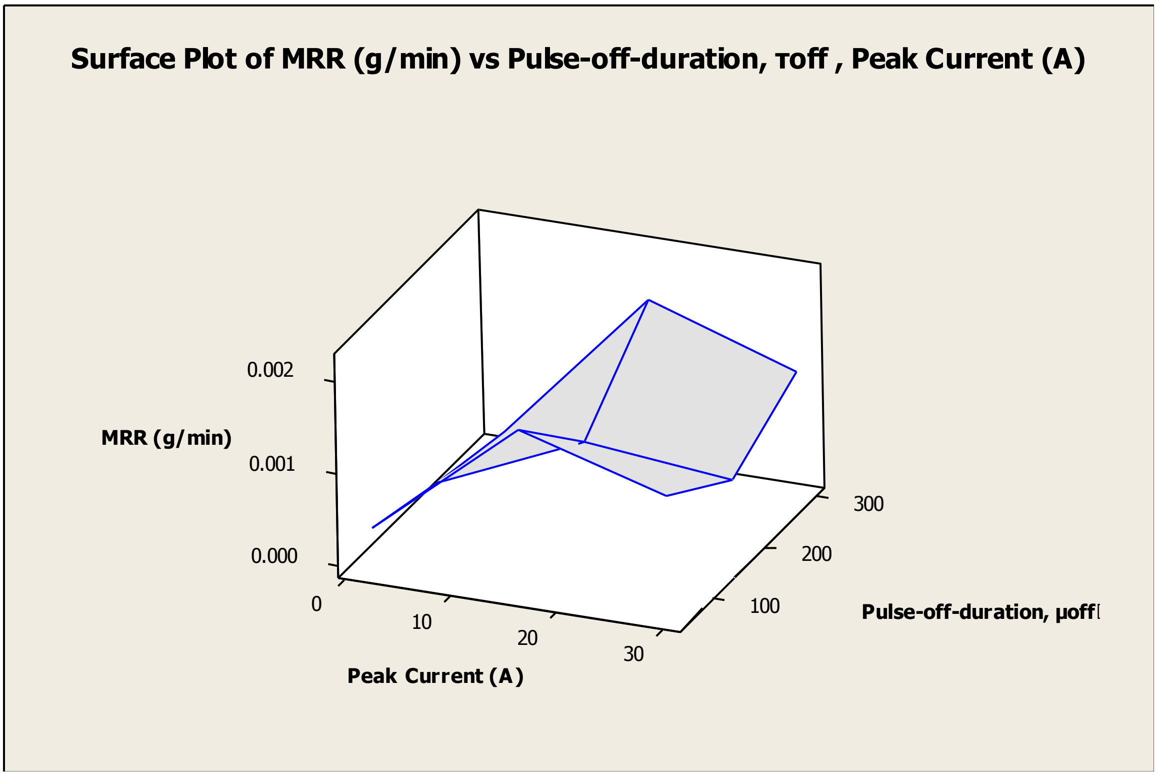


Figure 4.7 : Surface plot for MRR,Pulse-off-duration and Peak Current

Based on result on the table 4.6, its shows that peak current is the most significant factor that influence the experiment. According to the figure 4.7 it evidence that increasing peak current will increase the material removal rate.The increase of peak current generates high energy intensity and due to this energy melts more material from the workpiece. This will happen when increasing peak current, the potential different between the electrode with the workpiece also increase that make the intensity of the current increase. The factor of intensity is the one which most affects the MRR variables.

The impact of peak current and pulse off time on MRR are illustrated in the Figure 10. These 3-D surface plot shows that increasing peak current increases the MRR on the other hand the pulse off time exhibits dissimilar effect on MRR. At the range of discharge current 2- 23A, the MRR initially increases little and then decreases with increasing pulse off time however at the peak current >23 the MRR decreases with pulse off time. In another words, the short the pulse off time the more the MRR and the long the pulse off time the small the MRR while peak current >23. The insufficient interval time between pulse discharges results thermal overheating and a non uniform erosion of the workpiece. Thus, increase the pulse interval increases the MRR up to certain pulse off time. The cause of the second phenomenon is that during the pulse off time no energy is applied to the workpiece surface and results low MRR. Then again, since the time available for the application of heat energy on the workpiece surface, the top surface temperature of the workpiece increases as the pulse off time decreases. Thus, the material is eroded at faster rate and that commence MRR more at the short pulse off time. The same observation is reported by (M.K. Pradhan and C.K. Biswas , 2008),(J.Y. Kao and Y.S. Tarng, 1997) and (H.K. Kansal, S. Singh and P. Kumar,2008).

Higher MRR is required for only rough machining. Therefore the requirement of a higher MRR produces a very poor surface integrity. Besides that, higher current will shorten the machining time but it also will produce rough surface. Thus, optimum peak current are required in order to maximize MRR while minimize EWR and SR respectively.

Electrode wear ratio (EWR)

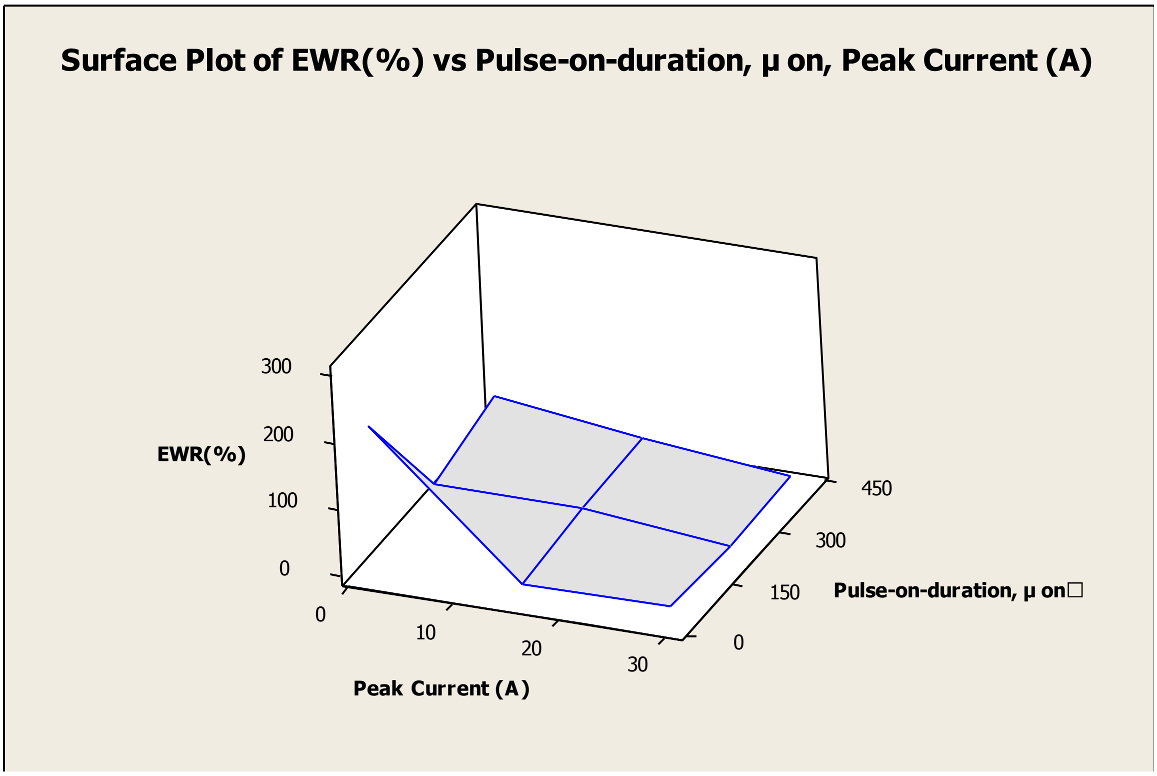


Figure 4.8 : Surface plot for EWR,Pulse-on-duration and Peak Current

Based on the table 4.7, its clearly show that the peak current is the most significant factors that affect the electrode wear ratio (EWR) of the electrode. The prime requirements of any electrode material are that good electrically conductive and less wear rate. According to the figure 4.8, EWR will increase at the initial increasing of peak current and will decrease almost flat when the peak current continue to increase also when the pulse on duration increase. Electrode wear is depending on the electrode materials and energy of the discharge. The higher the melting temperatures of the materials that will used, the lower are the electrode wear. An explanation to this may be given by, when using the low peak current it will increase discharge durations that promote more melting of material of the workpiece and solidification of the molten material of the electrode during the spark. Regarding the influence of pulse time on EWR, this is not the anticipated one, as EWR usually decreases when this last factor is increased or, what it is the same, when the sparks frequency is diminished.

The most influential factor on EWR is intensity in such a way that EWR decreases when this factor is increased, at least until a point after which it tends to increase within the work interval considered in this study. In practice, this is the behavior that one could expect a priori considering the experience on materials, as an increase in intensity is usually associated with a decrease in the electrode wear rate, although, if the intensity density through the section of the electrode is excessive, then an increase in EWR is produced. For EDM machining with copper-tungsten electrodes, higher the intensity will decrease the electrode wear rate. In part, this event can be explained as follows: the Cu-W alloy used as electrode material is composed of 30% Cu and 70% W, where the element tungsten has a melting point of 3410 0C; consequently, the high concentration of tungsten promotes better resistance of the electrode against the thermal wear degradation during machining. The result is a lower electrode wear rate and higher material removal rate. This causes a decrease of EWR when intensity increases.

Surface Roughness (SR)

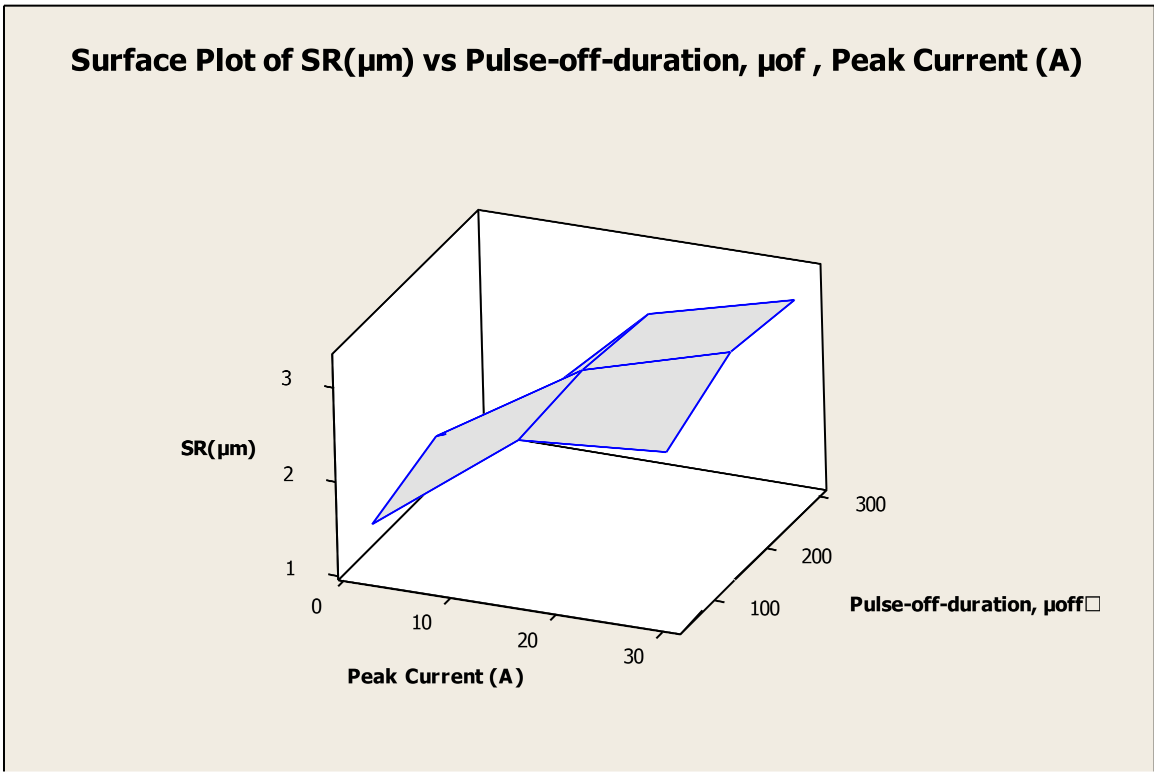


Figure 4.9 : Surface plot for MRR,Pulse-off-duration and Peak Current

Based on the table 4.8, peak current is also the most significant factors that influence the surface roughness. The increase of peak current increases the surface roughness. This is due to the fact that when peak current increase, more intensely discharges strike the surfaces and a great quantity of molten and floating metal suspended in the electrical discharge gap during EDM. As well as in a given pulse duration, the thermal energy which is induced in the workpiece through the spark is increased with pulse current. The higher the energy content of each spark, the more violent is the process, thereby generating a rougher surface. Thus increase peak ampere deteriorates the surface finish of the workpiece. The same observation has been reported by (H. Ramasawmy, and L. Blunt, 2004).Figure 4.9 shows that the pulse off time increase the surface roughness started to increase and hereafter decreases. If the peak current is too high, long pulse off time increases the SR. This is due to the fact that the pulse off time must be sufficiently long to acquire a uniform erosion of the material from the surface of the workpiece and stable machining process otherwise a non uniform erosion of the workpiece surface occurs. It is apparent in this research that the optimal pulse off time on behave of SR varies with ampere.

4.8 SIGNIFICANT FACTOR – PULSE-OFF TIME AND PULSE-ON TIME

Based on the ANOVA analysis, the second most significant factors that influence the experiment. Pulse-on time is The amount of time current runs into the gap before it is turned off. While, pulse-off time is the amount of time the current is off after making a single crater or pit to the workpiece.

4.8.1 Material Removal Rate (MRR)

Based on the table 4.6, its clearly show that the pulse-off time is the second most significant factors that affect the MRR. Figure 4.7 shows that increasing peak current increases the MRR on the other hand the pulse off time exhibits dissimilar effect on MRR. At the range of discharge current 2-30A, the MRR initially increases little and then decreases with increasing pulse off time however at the peak current >23 the MRR decreases with pulse off time. In another words, the short the pulse off time the more the MRR and the long the pulse off time the small the MRR while peak current >23. The reason of first observation can be explained as the pulse interval must be sufficiently long so that the plasma generated by the previous discharge can be deionized and the dielectric breakdown strength around the previous discharge location can be recovered (M. Kunieda, B. Lauwers 2005). The insufficient interval time between pulse discharges results thermal overheating and a non uniform erosion of the workpiece. Increasing the pulse interval increases the MRR up to certain pulse off time. During the pulse off time no energy is applied to the workpiece surface and results low MRR. Then again, since the time available for the application of heat energy on the workpiece surface, the top surface temperature of the workpiece increases as the pulse off time decreases. Thus, the material is eroded at faster rate and that commence MRR more at the short pulse off time.

4.8.2 Electrode wear ratio (EWR)

Based on result on the table 4.7, its shows that pulse on time is the second most significant factor that influence the experiment. According to the figure 4.8, EWR decrease as the pulse on time increase. EWR diminishes when intensity is increased but to a lesser extent for low values of pulse time, due to the existence of a statistically significant interaction between all the factors. Long pulse duration causes the more heat transfer into the sample and the dielectric fluid is unable to clear away the molten material, as the flashing pressure is the constant. In other words, while the pulse on time is increased the melting isothermals penetrate further into the interior of the material and the molten zone extends further into material and this produce a greater white layer thickness. As a result the increasing pulse on time decrease the electrode wear rate.

4.8.3 Surface Roughness (SR)

Based on the table 4.8, pulse off is the most significant factors that influence the surface roughness. According to the figure 4.9, the increasing of pulse off time will increase the surface roughness. If the discharge current is too high, long pulse off time increases the SR. This is due to the fact that the pulse off time must be sufficiently long to acquire a uniform erosion of the material from the surface of the workpiece and stable machining process otherwise a non uniform erosion of the workpiece surface occurs. Another reason is that the long pulse off time furnishes good cooling effect and enough time for flush away the molten material and debris from the gap between the electrode and workpiece. Thus, long pulse off time present fine surface of the workpiece and the same effect is achieved in (K.L. Wu, B.H. Yan, 2009).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

Based on this experiment, the use of the orthogonal array to optimize the edm process with the single performance characteristics of the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) has been reported in this paper. The optimum condition of the edm process are can be achieve by using the method proposed in this study.

5.2 CONCLUSION

For the main conclusions that obtain during the study are as follow:

1. After all result have been analyze, peak current give the most significant factor that will affect the MRR, EWR and SR of the process.
2. MRR can been increase if the peak current also increase, but it`s still give the effect to EWR and SR.
3. Increasing the peak current, pulse-on time and servo voltage increase the rate of MRR while reduce EWR and SR.
4. ANOVA is very usefull to determine the most significant parameter that will affect the process performance characteristic when there are many parameter involved.

5.3 RECOMMENDATIONS

1. When calculate ANOVA, there is various statistic software that can be use such as, STATISTICA, MINITAB, MICROSOFT EXCEL and so on rather than calculate manually that will take time to finish and maybe have some error while doing the project.
2. For future research, maybe can use the others combination of workpiece and electrode that can give better characteristic of machining EDM performance.

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APPENDIX A1

Table for control factors

Factors	**Description**	**Level 1**	**Level 2**	**Level 3**	**Units**
A	Polarity, *P*	Workpiece (+) Tool (-)	Workpiece (-) Tool (+)	-	Positive (+) Negative (-)
B	Peak Current (A)	2	16	30	Ampere
C	Pulse-on-duration, μ_{on}	10	205	400	microsec
D	Pulse-off-duration, μ_{off}	50	175	300	microsec
E	Servo Voltage	40	70	90	V

Table for workpiece

Experiment number	Work Piece	Before	After	Result
1	2	14.4012	14.3726	0.0286
2	3	14.1429	14.0998	0.0431
3	5	14.4053	14.3982	0.0071
4	6	14.4126	14.3765	0.0361
5	7	12.9299	12.8923	0.0376
6	8	14.1646	14.1213	0.0433
7	9	14.1197	14.0785	0.0412
8	10	13.6274	13.5843	0.0431
9	11	14.1899	14.1486	0.0413
10	12	14.3519	14.3483	0.0036
11	13	12.8639	12.8329	0.0310
12	14	12.9361	12.8988	0.0373
13	15	14.1208	14.0837	0.0371
14	16	14.3840	14.3464	0.0376
15	17	14.2060	14.1593	0.0467
16	18	14.4435	14.4015	0.0420
17	19	12.8538	12.8112	0.0426
18	20	14.1104	14.0613	0.0491

Table for electrode

Experimentnumber	Before	After	Result
1	7.4027	7.3616	0.0411
2	6.4913	6.4855	0.0058
3	7.5819	7.5755	0.0064
4	7.1151	7.1068	0.0083
5	6.9592	6.9480	0.0112
6	7.1089	7.0937	0.0152
7	7.3093	7.2986	0.0107
8	7.5233	7.5217	0.0016
9	7.1644	7.1578	0.0066
10	7.3616	7.3509	0.0107
11	6.4855	6.4695	0.0160
12	7.5755	7.5606	0.0149
13	7.1068	7.1016	0.0052
14	6.9480	6.9352	0.0128
15	7.0937	7.0774	0.0163
16	7.2986	7.2932	0.0054
17	7.5217	7.5155	0.0062
18	7.1578	7.1510	0.0068

Table L18 Orthogonal Arrays

Exp	A	B	C	D	E	Result		
						MRR	EWR	SR
1	1	1	1	1	1			
2	1	1	2	2	2			
3	1	1	3	3	3			
4	1	2	1	1	2			
5	1	2	2	2	3			
6	1	2	3	3	1			
7	1	3	1	2	1			
8	1	3	2	3	2			
9	1	3	3	1	3			
10	2	1	1	3	3			
11	2	1	2	1	1			
12	2	1	3	2	2			
13	2	2	1	2	3			
14	2	2	2	3	1			
15	2	2	3	1	2			
16	2	3	1	3	2			
17	2	3	2	1	3			
18	2	3	3	2	1			

Result of Experiment

Exp	A	B	C	D	E	Average values for		
						MRR (g/min)	EWR (%)	SR (μm)
1	+	2	10	50	40			
2	+	2	205	175	70			
3	+	2	400	300	90			
4	+	16	10	50	70			
5	+	16	205	175	90			
6	+	16	400	300	40			
7	+	30	10	175	40			
8	+	30	205	300	70			
9	+	30	400	50	90			
10	-	2	10	300	90			
11	-	2	205	50	40			
12	-	2	400	175	70			
13	-	16	10	175	90			
14	-	16	205	300	40			
15	-	16	400	50	70			
16	-	30	10	300	70			
17	-	30	205	175	90			
18	-	30	400	50	40			

APPENDIX B2

Gantt Chart FYP 1

WEEK TASK		W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
1) Briefing on PSM	**Planning**	🟦	🟦													
	Actual	🟥	🟥													
2) Meeting with supervisor/co-supervisor	**Planning**	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
	Actual	🟥	🟥	🟥	🟥			🟥	🟥			🟥	🟥	🟥		
3) Preparation/submit project's proposal	**Planning**	🟦	🟦													
	Actual	🟥	🟥													
4) Literature review	**Planning**			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦				
	Actual			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥				
5) Learning CNC EDM machine	**Planning**						🟦	🟦	🟦	🟦	🟦					
	Actual						🟥	🟥	🟥							
6) Preparation For Methodology	**Planning**										🟦	🟦	🟦	🟦	🟦	
	Actual										🟥	🟥	🟥	🟥	🟥	
7) Writing report	**Planning**	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
	Actual	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
8) Presentation of FYP 1	**Planning**															🟦
	Actual															🟥

APPENDIX B3

Gantt Chart FYP 2

Activity	Week	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
1) Specimen preparation	Planning	🟦	🟦	🟦	🟦											
	Actual		🟥	🟥	🟥	🟥										
2) Experimental -Machining	Planning			🟦	🟦	🟦										
	Actual				🟥	🟥	🟥	🟥	🟥	🟥	🟥					
3) Characterization -W/P& tool mass loss & SR	Planning				🟦	🟦	🟦									
	Actual						🟥	🟥	🟥	🟥	🟥					
4) Writing- Ch 4 (result & characterization)	Planning						🟦	🟦	🟦	🟦						
	Actual							🟥	🟥	🟥	🟥	🟥	🟥			
5) Writing- Ch 5 (discussion)	Planning							🟦	🟦	🟦	🟦	🟦				
	Actual								🟥	🟥	🟥	🟥	🟥			
6) Writing Paper	Planning										🟦	🟦	🟦			
	Actual										🟥	🟥	🟥			
7) Submit to supervisor	Planning											🟦	🟦			
	Actual											🟥	🟥			
8) Thesis Draught Correction by supervisor (3 times)	Planning									🟦	🟦	🟦				
	Actual									🟥	🟥	🟥				
9) Final year project 2 Presentation	Planning													🟦	🟦	
	Actual													🟥	🟥	
10)Check the whole thesis with second reviewer	Planning														🟦	🟦
	Actual														🟥	🟥
11) Summit the thesis	Planning														🟦	🟦
	Actual														🟥	🟥